Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

MAINSTREAMING PHOTOVOLTAICS FOR RESIDENTIAL ROOFTOPS

Prepared for: California Energy Commission
Prepared by: PowerLight Corporation

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Mainstreaming Photovoltaics (PV) for Residential Rooftops is the final report for the Sacramento Municipal Utilty District ReGen project (Contract Number 500-00-034), conducted by PowerLight Corporation. The information from this report contributes to PIER's Renewable Energy Technologies Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916 327-1551.

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Abstract

PowerLight was successful in three parallel design processes, producing three market-ready products suited to various types of residential customers.

This report describes the development process for each of the three products along with the testing and certification work and the development of manufacturing and quality processes. For all three products, the project team set up supply chains and selected manufacturing partners produced prototypes.

The three products have additional value-added features beyond electricity production from sunlight. All three products reduce the transfer of heat into the building space. The two flat roof products install without the use of fasteners penetrating the roof membrane. The shingle tile incorporates a vented cavity to keep photovoltaic temperatures low and maximize operating efficiency.

PowerLight's marketing research showed a largely untapped market in flat roof multi-unit residential housing. The scope of this project was re-worked to include three product development efforts rather than just the original sloped roof design.

PowerLight made significant progress through this contract with the Sacramento Municipal Utility District and the California Energy Commission. This will help reduce photovoltaic installation cost, decrease California's reliance on imported energy, and improve the lives of California's citizens by reducing pollution and the cost of energy.

Keywords: Solar, photovoltaic, PV, PV array, building-integrated PV

Executive Summary

Introduction

The technical objectives set out at the beginning of this project have led to the development of high-value photovoltaic (PV) products. The successful launches of these new PV products provide broad target groups with aesthetically pleasing, safe, market-ready, affordable PV options.

Purpose

The project goal was to produce an affordable, high-performance, aesthetically appealing, easily installed, standardized/certified, grid-tied residential PV system that slashes consumers' energy bills and eases demand loads on the utility grid. The product's design would be, in target geographic areas, a generally accepted roofing option for all existing (retrofit), re-roofing, and new home construction.

Project Objectives

PowerLight's marketing research showed a largely untapped market in flat roof multi-unit residential housing. The scope of project was then expanded from the original sloped roof design to the development of three products that will address the needs of sloped-roof, single-family residential buildings as well as flat-roof, multi-family residential buildings. The new products are designed for new or retrofit and building-integrated applications. They are simple to install, integrated wiring, interconnection and mounting system, accessible, and expected to meet Title 24 requirements. The three products are identified in Figure 1 below.

Figure 1: Product development paths

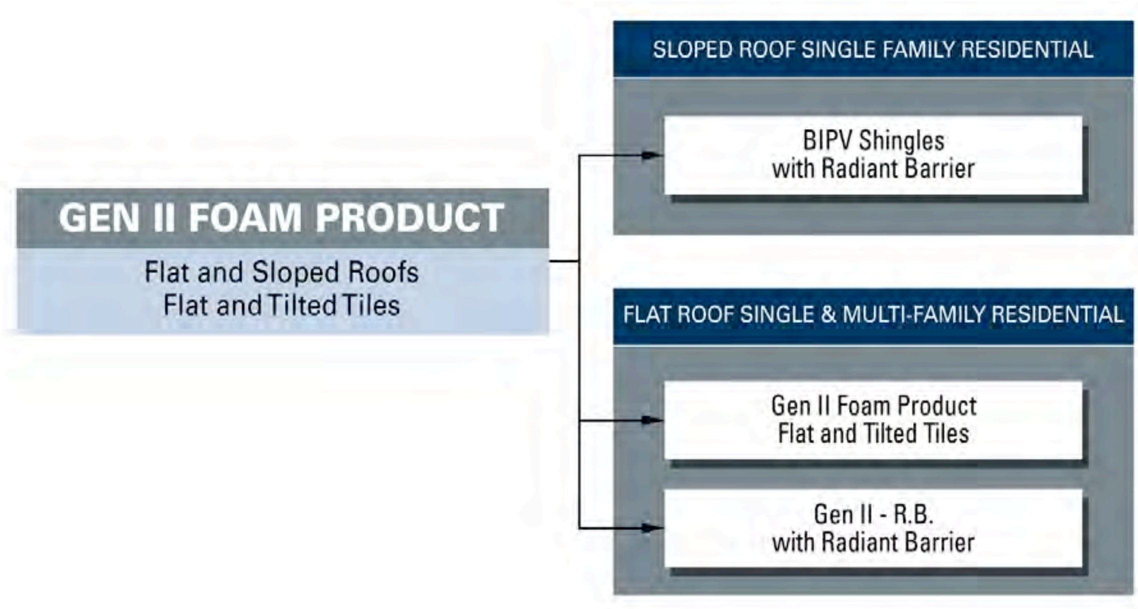

Photo Credit: PowerLight Corporation

Project Outcomes

The shingle product went through several concept designs. The project installed a 2 kilowatt demonstration array on Sacramento Municipal Utility District property, and the design received a positive response from a variety of building and PV industry representatives. Design changes followed the installation of the demonstration array based on lessons learned from that installation, as well as information gained during developmental testing at Underwriters Laboratories. Certification testing is underway to prepare for a full-scale product launch.

The project team worked on two versions of the Gen II Insulated tile for flat roof, one with a sloped PV module and one with a flat PV module. The team installed demonstration systems using the sloped PV module. PowerLight set up a manufacturing line in its Berkeley factory to produce the units for these projects.

Powerlight abandoned the effort to develop a flat PV version of this product when the company was unable to find capsheet material to cover the foam backerboard that would meet both the fire rating performance and cost targets required to make the product marketable. The project team performed pilot runs for early prototypes of this product, but did not complete commercial projects.

The Gen II Radiant Barrier Tile for flat roof went through several designs, finally taking the form of a field-assembled system using a minimum of tools and loose hardware. The project team installed a large system at a customer's site and a small demonstration system within SMUD territory for testing purposes. They sold and installed a second large system in July 2005. This was the first commercial system with this product in California.

The following report details information regarding the three different products developed under this project: Shingle Tile with Radiant Barrier for Sloped Roofs, Gen II Insulated Tile for Flat Roofs and Gen II Radiant Barrier Tile for Flat Roofs.

Conclusions

PowerLight completed three parallel rooftop PV system design processes for three market-ready products suited to the various types of residential customers. These products are intended to address the needs of sloped-roof, single-family residential buildings as well as flat-roof, multi-family residential buildings.

Recommendations

The project team recommends that further research continue in the areas of electrical performance, thermal performance, and cost reduction for all three products described in this report. Additional funding for these products is required to further technical developments and reduce barriers to market acceptance. Barriers include, but are not limited to:

- Initial capital cost.
- Availability of system financing vehicles.

- Lack of technical expertise among code officials.
- Lack of general public awareness of solar electricity benefits and characteristics.
- Lack of common net metering and interconnection standards nationally.

Addressing these barriers could expand the national market, as well as enable California manufacturers to compete in the global marketplace.

Benefits to California

The achievements realized during this project provide many benefits to the citizens of California. The technical objectives set out at the beginning of this project led to the development and commercial availability of a high-value PV product for sloped-roof buildings, as well as new high-value PV products for flat-roof buildings. The progress made toward these goals will do much for California building owners in reducing energy costs, both through lowering consumption and maximizing PV output.

The Underwriter Laboratories listing and Class A fire rating for the residential sloped roof product will streamline the permitting process and boost developers' and building inspectors' confidence in the safety of the product. With the PV shingles designed to work with an existing and well-known roofing product, market penetration can be accelerated, allowing California homeowners to enjoy the benefits of the new building integrated PV products more quickly. The final electrical wiring design allows for easy removal of any PV laminate and easy access to the electrical connections when removing laminate. The long design life of the product and the ease of replacement will keep maintenance costs of the system to a minimum, providing maximum return on the homeowner's investment. Initial feedback from industry representatives and customers indicated the aesthetics of the new product have been well received. The design blends well with roofing tiles that builders use in many new California home developments.

The new products are designed for new or retrofit and building-integrated applications. They are simple to install using traditional roofing practices. Electrical wiring and interconnection are integrated into the mounting system and are accessible after installation. Electricity and thermal performance is expected to be capable of recognition by California Energy Commission Title 24 Building Efficiency Standards. This will accelerate the spread of the new products, allowing California building owners a way to reduce their energy costs in the very near future.

The products are expected to meet the commercialization objectives of the project. PowerLight continues to work on lowering product costs. The successful launch of these new products provides many benefits to the people of California. Through funding assistance from the Sacramento Municipal Utility District and the California Energy Commission's Public Interest Energy Research Program, PowerLight Corporation is making solar power more affordable.

Solar-electric power systems provide a domestic source of energy that is plentiful, sustainable, and available throughout the United States. PV systems transform clean, abundant solar energy into electricity, are virtually maintenance free, and provide an economic hedge against volatile fossil fuel prices. These on-site solar systems provide renewable power for more than 30 years and offset purchases of expensive “peak” utility electricity. Solar powered installations spare the environment from thousands of tons of harmful emissions, such as nitrogen oxides, sulfur dioxide, and carbon dioxide, which are major contributors to smog, acid rain, and global warming. One megawatt of solar installations will reduce emissions of nitrogen oxides by an estimated eight tons and carbon dioxide by 32,000 tons. Building a PV infrastructure provides insurance against the threat of global climate change.

In the past, the main problem with generating electricity from the sun through PV has been cost. Direct results of California’s continued commitment to this indigenous resource are economic development and the associated job growth. The widespread adoption of PV technologies will stimulate further realization of these benefits.

1. Shingle Tile with Radiant Barrier for Sloped Roofs

1.1 Introduction, Background and Overview

1.1.1 Problem Statement

Several building-integrated PV (BIPV) products are available on the market. However, sales of these products have been limited to niche markets, i.e. off-grid, rural locations. In an effort to promote the expansion of the market for PV systems on residential buildings, PowerLight Corporation embarked on this three-year product development effort.

The goal of this project was to produce an affordable, high-performance, aesthetically appealing, easily installed, standardized/certified, grid-tied residential PV system that slashes consumers' energy bills and eases demand loads on energy grids. The product would be designed to be, in target geographic areas, a generally accepted roofing option for all existing (retrofit), re-roofing, and new home construction.

In this section of the report, the authors will discuss PowerLight's approach to designing this sloped-roof product, the results that were achieved, and a comparison of the results with the project goals in terms of electrical performance, thermal performance, and cost. This section will also discuss conclusions regarding residential markets, the product development process, and the commercialization potential for this product.

1.1.2 Overview of Existing Products at Project Start

At the start of this project, PowerLight offered both roof and ground mounted PV systems for commercial applications, while having limited product development on residential applications. PowerLight had completed some development work on a shingle-style PV tile designed for sloped roof applications. This work was done as part of a Small Business Innovation Research (SBIR) contract through the U.S. Department of Energy. PowerLight and SMUD embarked on this project to leverage the work PowerLight had done on this product as well as PowerLight's experience with flat-roof PV systems to create a high-value residential PV product. The preliminary prototypes of the sloped roof product had undergone performance testing at the Florida Solar Energy Center (FSEC) and the electric and thermal performance was promising.

Figure 2: Early prototype shingle tiles under test
Photo Credit: PowerLight Corporation

1.2 Project Objectives

The product was to meet the following technical performance objectives:

1. Adds insulation value of R-50 to the rooftop (both PV and non-PV tiles, which go around the PV array and on the roof's north slope).
2. Maintains PV cell temperatures at relatively cool, "rack-mount" levels, unlike other direct-mounted, building-integrated PV products, resulting in 10 to 18% higher module output.
3. Certified by Underwriters Laboratories (UL), International Conference of Building Officials (ICBO), and Institute of Electrical and Electronics Engineers (IEEE).
4. Designed for retrofit and building-integrated applications, both waterproof assemblies.
5. Installed simply using traditional roofing practices, including waterproofing, and edge, ridge, and eave details. PV modules snap into a pre-engineered mounting system, easily done by one person on a sloped roof surface.
6. Integrated electrical wiring and interconnection into the mounting system and are accessible after installation.
7. Obtain recognition by California Energy Commission Title 24 for electricity and thermal performance.
8. Has a 50-year design life and increases roof durability.

The product was to meet the following economic and commercial potential objectives:

1. Target cost of materials $1.50/square foot (sf) over the cost of PV.
2. Insulation value $0.15 to $0.30/sf added to product value.
3. Aesthetics that fit traditional roofing criteria. Customer choice of background color and appearance, and, for non-PV tiles, color, texture, and shape.

4. Designed for retrofit, reroofing, and new construction applications.

The result of this project was to be a market-ready product meeting the objectives listed above, which improves upon existing residential PV roofing products in terms of cost, ease and speed of installation, and electrical and thermal performance.

High-volume manufacturing was to allow this product to be purchased in megawatt quantities by utilities at low cost, to offer to their residential customers. The target cost was below that of comparable products available at the start of this project.

1.3 Project Approach

The first step in the development of this product was the creation of a detailed product specification. In order for the product specification to lead to a successful product, market requirements must be taken into account. A preliminary specification was created at the beginning of this project, and then it was modified based on market research described in Section 1.4 below. The key points of the product specification are described in Section 1.5 below. Once this was defined, the development process proceeded as described in Section 1.6. As the product design proceeded, testing took place in-house to ensure that the final design would pass all necessary certification testing. The testing also served to provide feedback to the product design engineers on the efficacy of each design iteration. Manufacturing processes were developed as the design work progressed.

An important part of the development process was the evaluation of the market requirements and customer preferences. To address this, a meeting was organized to bring together representatives of the construction, roofing, and photovoltaic industries to evaluate the prototype design and provide feedback. This is discussed in Section 1.4 below.

1.4 Discussion of Residential Markets and Roof Types

PowerLight's original plan was to conduct focus group studies to determine the market requirements for a sloped roof product. PowerLight's market experience was in the sale of flat roof, industrial PV systems, so the sloped roof residential market was not as well understood. Some initial work was done to determine how best to conduct a focus group study, and PowerLight decided, with input from SMUD, that it would be better to assemble a group of representatives from the roofing, housing development, and PV industries and present the design concept to them. This would provide an opportunity to get direct feedback from the target industries on what issues were important to potential customers and installers. This presentation was done in conjunction with the critical project review in July 2004. The results of this meeting are given below.

1.4.1 Mechanical Design Considerations

The participants were generally enthusiastic about the mechanical design. Specific feedback included:

- The shingle appears to be compatible with commonly used roof tiles.

- The installation has a high part count—fewer parts would be better. This concern was addressed in later design iterations.
- The ability to walk on the PV is desirable, but not a deal-breaker.
- One participant did not feel that venting material being used was effective in stopping wind-driven rain. This was changed in later design iterations.
- A Class "A" fire rating is required.
- Some participants did not feel that the radiant barrier's contribution to load shedding would be worth the cost.
- Participants generally felt that the vented cavity was an advantage (increased PV efficiency).

1.4.2 Electrical Design Considerations

- Elimination of grounding is key.
- High efficiency PV could have advantages, especially if future incentives are performance-based.
- Interconnection of modules should be made "idiot-proof."

1.4.3 Installation

- The method of installation was generally felt to be straightforward and in line with standard roofing practices.

1.4.4 Warranty/Replacement Issues

- Participants expect solid backing by the PV system supplier and industry-standard warranties (20-plus years).
- The entire turnkey system should be covered by a single warranty to provide the customer with a single point of contact.

1.4.5 Marketing, Sales and Support Issues

These issues were important for the participants in the discussion, which was dominated by housing developers. Specifically:

- Rebates need to be handled by PowerLight. The developers are not experienced with the rebate process, and it will be a powerful disincentive if they are left to deal with it themselves.
- PowerLight should be capable of supplying a turnkey system including PV, disconnects, and inverter. These should all be under the same brand name. Potential customers will be more comfortable with a single supplier who will support the entire system.

- Customer support is very important, including a toll-free hotline and local representatives to help with any installation issues.
- Installation cost needs to be less than $1/Watt.
- The ultimate goal for the complete system price needs to be less than $4/Watt installed.

1.4.6 General Comments

- Cost is the primary factor in a decision to choose one product over another.
- Shingles should be zero maintenance.
- One reviewer commented that this was the best product out of the last three he has seen.
- One reviewer commented that this product would give the competition a run for their money.

1.4.7 Discussion Conclusions

Overall, the experts were very positive concerning the new design. Some early interviewees who provided initial feedback were concerned with waterproofing and PV performance. The participants in this discussion were mostly concerned with price, ease of installation, and installation and warranty support from the manufacturer.

1.5 Product Specification

Key attributes of PowerLight's photovoltaic shingle product include:

- A design that integrates seamlessly with market-leading concrete roofing tiles and standard construction methods.
- No grounding required through innovative use of materials.
- PV modules with industry-leading efficiency to allow for fewer installed modules for given output.
- Vented cavity configuration that cools the modules, allowing even higher operating efficiency.
- Integrated radiant barrier option to increase whole-house energy efficiency.
- A design that allows for easy module replacement in the event of breakage.

As mentioned in Section 1.4 above, a Class A fire rating was deemed a requirement based on the industry feedback. As a result, some of the materials in the tile design had to be changed from plastic to metal in order to survive the fire testing. This made it necessary to abandon the concept of a non-grounded tile.

1.6 Development Process

The initial development effort for a sloped roof product was focused on adapting the insulated tile for flat roof to a sloped roof configuration. Some prototypes were made and installed on a small demonstration roof in PowerLight's test lab. These are shown in Figure 3.

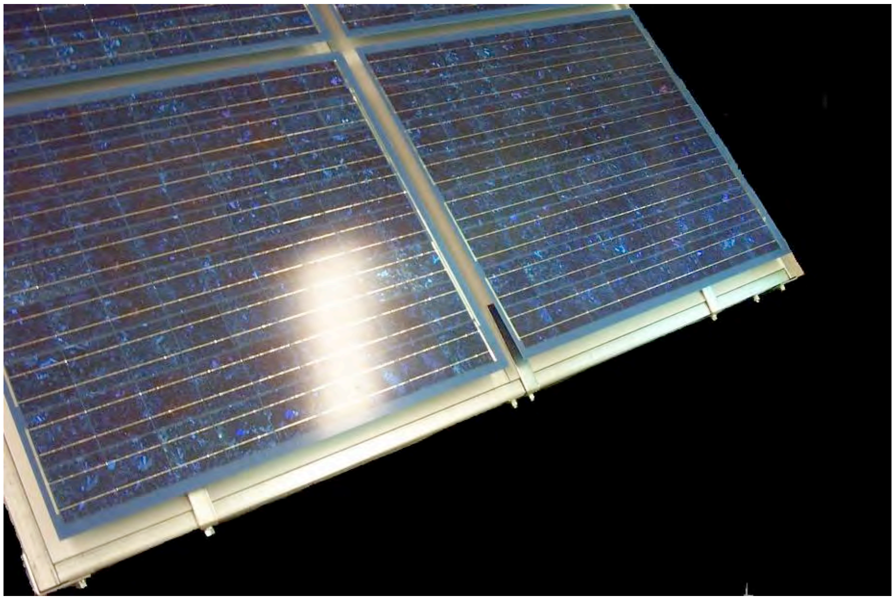

Figure 3: Early sloped roof product prototypes
Photo Credit: PowerLight Corporation

Renderings of this product on sloped roofs were made to test the viability of the product within a target market. One of these renderings is shown in Figure 4.

Figure 4: Rendering of insulated product on sloped roof
Photo Credit: PowerLight Corporation

At this point, it was decided that the adaptation of the Insulated Tile for flat roof to a sloped roof did not produce a marketable product. The development effort returned to the shingle-style concept that had been pursued prior to the start of this project.

The goal of the design process was an overlapping shingle-style tile incorporating a radiant barrier to minimize heat transfer into the attic space and a vented cavity behind the PV module to allow convective cooling of the module. At first, this design effort focused on the use of metal shingles. A tile was designed using a base that was similar to a common type of metal roofing shingle. The PV module would be mounted to brackets that would hold the PV module away from the roof surface, providing the ventilation for cooling, and the metal base itself would act as the radiant barrier. Prototypes of this design were constructed, and it, too, was determined to be unmarketable due to aesthetic concerns.

The metal shingle concept was abandoned at this point, and a design was created to mate with a concrete roofing tile that is used in a large percentage of new housing construction. The new design retained the ventilation to cool the PV module, but the radiant barrier was moved to the surface of the roof below the tiles. An off-the-shelf material referred to as Peel-and-Seal is available with an aluminum top layer providing the desired radiant barrier properties. Several sets of proof-of-concept prototypes were constructed. A mock-up of a roof with two prototype tiles was constructed and shown to a panel of construction and PV industry representatives. The new design was greeted with an enthusiastic response. The comments were used to produce another iteration of the design, and a 2 kW demonstration array was installed on SMUD property.

The demonstration array was installed by Roseville Electric, a contractor with experience in PV installations. Comments received from Roseville Electric and the PowerLight employees who took part in the instrumentation of the array were used to do another iteration of the design.

The demonstration array was installed with the tiles lined up vertically. This necessitated the use of a piece of metal flashing between each tile and requiring that some of the concrete tiles be cut in half at the edges of the array. The installation of the flashing represented a significant amount of the installation time, and the need to cut tiles, while a common practice, adds labor to the process. The design was changed to allow the tiles to be installed in a staggered configuration. This eliminated the need to cut concrete tiles at the edge of the array. An extruded edge guard was incorporated into the tile assembly removing the need for the flashing. The material used at the lower edge of each tile to prevent rain water from being blown under the tile was replaced with a more robust material. The brackets at the lower edge of each tile were made from metal for the demonstration array. The intent was to replace the exposed metal parts with a non-conductive material that would remove the need to ground each tile, reducing material cost and installation labor. Subsequent testing for a UL fire rating has shown that it will be difficult to use a non-metallic material in this application, so a grounding requirement may be unavoidable.

1.7 Final Product

As described in Section 1.6 above, the Radiant Barrier Tile for sloped roof is designed to mate with commonly used concrete roofing tiles. The design has gone through two design iterations following the installation of the demonstration array. The first iteration was based on the lessons learned during the manufacture and installation of the tiles for the demonstration array. The second design iteration was based on feedback obtained during fire rating tests performed at UL. In order to obtain a Class A fire rating, the design of the vented cavity had to be modified. The later design passed the Class A fire test during a series of developmental tests at UL, but with a higher cost. PowerLight is working on modifying this design so that it can pass the Class A fire test and still be affordable.

1.8 Manufacturing Process

The Radiant Barrier Tile for sloped roof will be assembled in PowerLight's Berkeley factory for at least the first year of production. As the volume ramps up, the assembly work may be done by a subcontractor, once a suitable partnership could be set up. A relatively simple production line has been designed to manufacture these tiles. The following photographs show the manufacturing line and process for the Shingle Tile with Radiant Barrier for Sloped Roof. The tiles shown in these photographs were made for testing and for the demonstration array. Many of the parts have changed somewhat during the subsequent design iterations, but the assembly process will be largely the same.

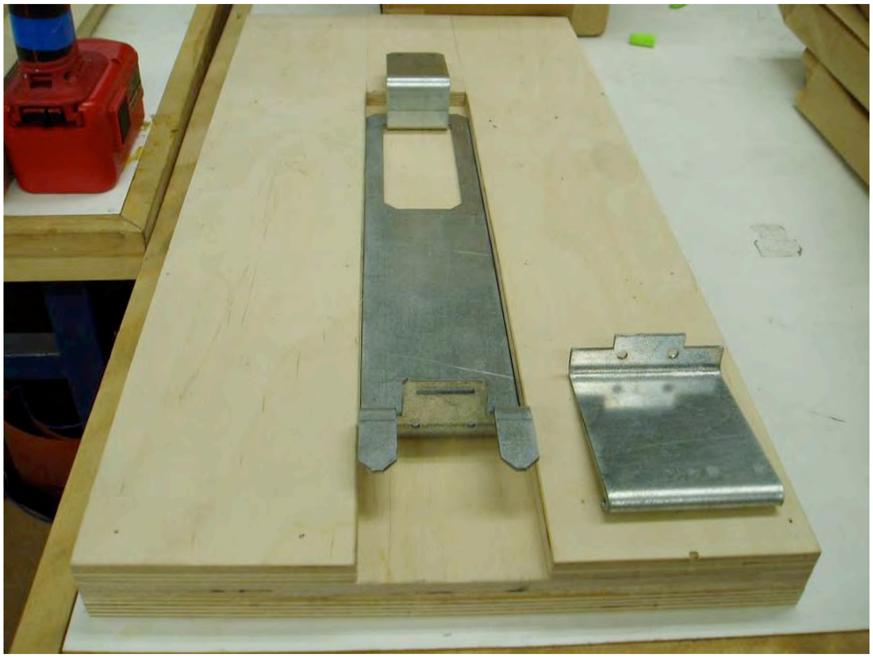

Figure 5: Bracket assembly fixture
Photo Credit: PowerLight Corporation

Figure 6: Tile assembly fixture
Photo Credit: PowerLight Corporation

Figure 7: Positioning PV laminate in fixture
Photo Credit: PowerLight Corporation

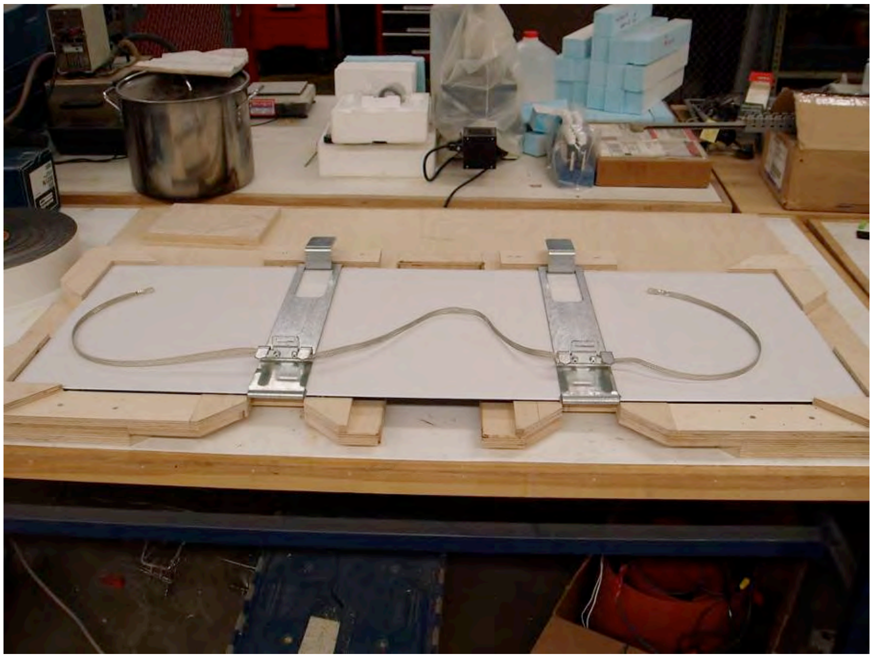

Figure 8: Mounting brackets installed
Photo Credit: PowerLight Corporation

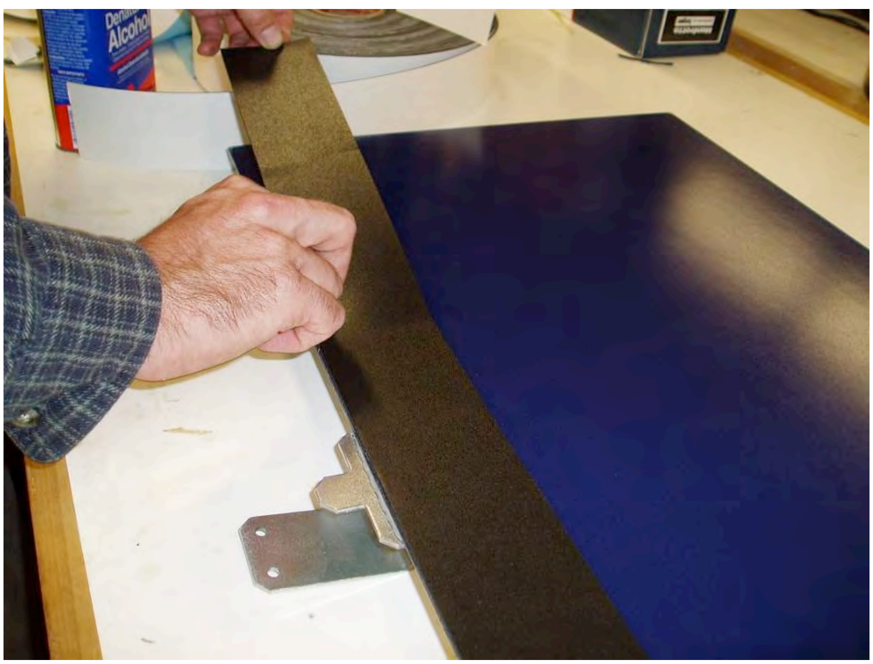

Figure 9: Protective film application
Photo Credit: PowerLight Corporation

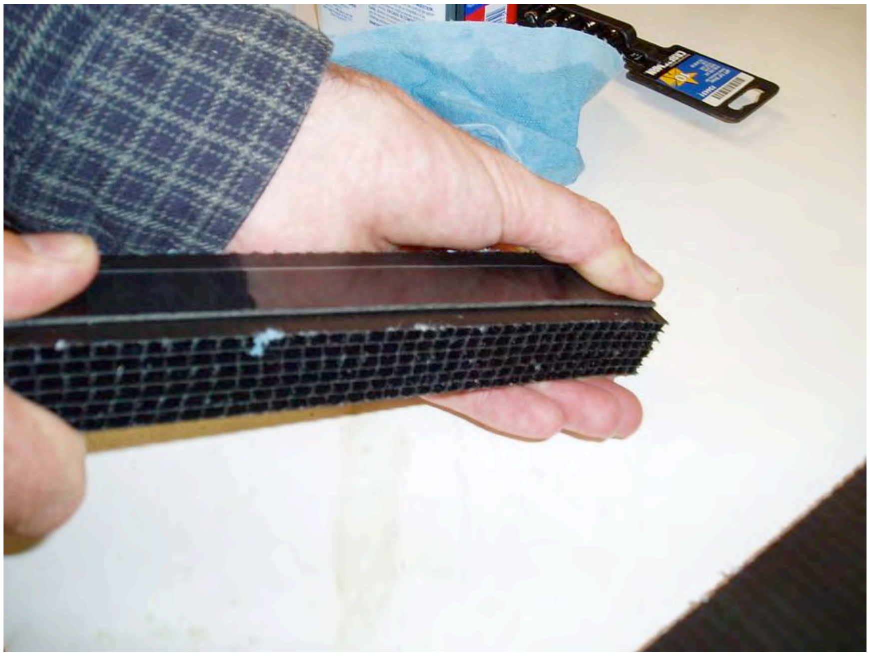

Figure 10: Vent application
Photo Credit: PowerLight Corporation

Figure 11: Completed tile
Photo Credit: PowerLight Corporation

For large scale production, the PV modules will be made to PowerLight's specifications using high efficiency cells. These cells are black, and the background color of the modules will be made to blend with the color of the concrete tiles being used.

1.9 Production Data and Photos

The tiles for the demonstration array were made using the fixtures shown in Section 1.8 above. Figure 12 and Figure 13 show the installation of the demonstration array.

Figure 12: Shingle tiles being installed
Photo Credit: PowerLight Corporation

Figure 13: Completed array
Photo Credit: PowerLight Corporation

1.10 Certifications

As with the Gen II Insulated Tile for flat roof, PowerLight implemented a comprehensive internal test program for the Shingle Tile that duplicates the certification tests prior to submitting the design to UL and ICC. Some developmental fire rating tests were done at UL due to the difficulty of setting up and operating an equivalent fire test in PowerLight's laboratory. The purpose of this testing program was to ensure that the design submitted would pass the actual certification testing. The certification testing is a lengthy and expensive process, so it was important to go through it only once, after the design reached its final form.

PowerLight has applied for UL and ICC certification of the Shingle Tile for sloped roof. This certification is pending testing by each of the certification organizations.

1.11 Electrical Performance

The demonstration array was connected to a prototype SMA America inverter that charged a large battery backup and powered a DC lighting system. Because of the battery backup and DC load the electrical performance of the array was evaluated by measuring the power output on the DC side of the inverter. A voltage divider and Hall Effect current sensor were installed in the DC disconnect box. The data acquisition system (DAS) measured the voltage and current from the sensors and calculated the power produced by the array.

A meteorological station, consisting of a pyranometer, a shielded temperature probe, a weathervane, and an anemometer, was installed 6 feet above the north wall of the shed on which the array was installed. All sensors from the meteorological station were connected to the DAS. The ambient conditions measured by the meteorological station were used in determining the thermal and electrical performance of the Shingle Tile array.

Using the information collected from the voltage and current sensors and the pyranometer, the efficiency of the Shingle Tile was evaluated. The project team chose February 28 for analysis because it was a typical high irradiance day for that month. Also, the ambient and PV temperatures during that day were too low to have a significant influence on the performance. Between 1 p.m. and 1:15 p.m., an average irradiance of 722 W/m^2 and an average power reading of 1304 W (on the DC side) was measured.

The predicted output for the PV array under this irradiance was 1432 ± 157 W. The large uncertainty of this prediction is mostly due to the fact that the PV supplier's specification gives a 10% range on the power rating of the modules. This, combined with the accuracy of the pyranometer, yields an uncertainty of 11%. The actual power measured under this irradiance was 1304 ± 54 W. This is at the bottom edge of the prediction error band, possibly indicating that the system is not performing to its full potential.

There are several reasons why the actual performance would be lower than the prediction such as soiling, light-induced degradation, or a high-resistance connection somewhere in the system. An I-V curve test would determine the actual power rating of the modules. Thermal data indicate that the modules are not overheating, so the project team could rule that out as a cause of the low power output. Also, by checking the output of the system before and after cleaning, the effects of soiling on system performance could be determined. PowerLight will endeavor to perform these tests to fine-tune the system performance measurements.

1.12 Thermal Performance

From the time data collection began to the time the system monitoring report was prepared there was only one day of data collected for ambient temperatures over 72°F. On October 15, 2004, the ambient air temperature rose to a maximum of 81.9°F and maintained a temperature over 78°F for the time between 1:15 p.m. and 6 p.m.

Figure 14 and Figure 15 show the temperature data for the complete thermocouple stacks at Locations 3 and 7 as defined by Figure 16. These are the center locations of the areas covered by Shingle Tiles and MonierLife tiles.

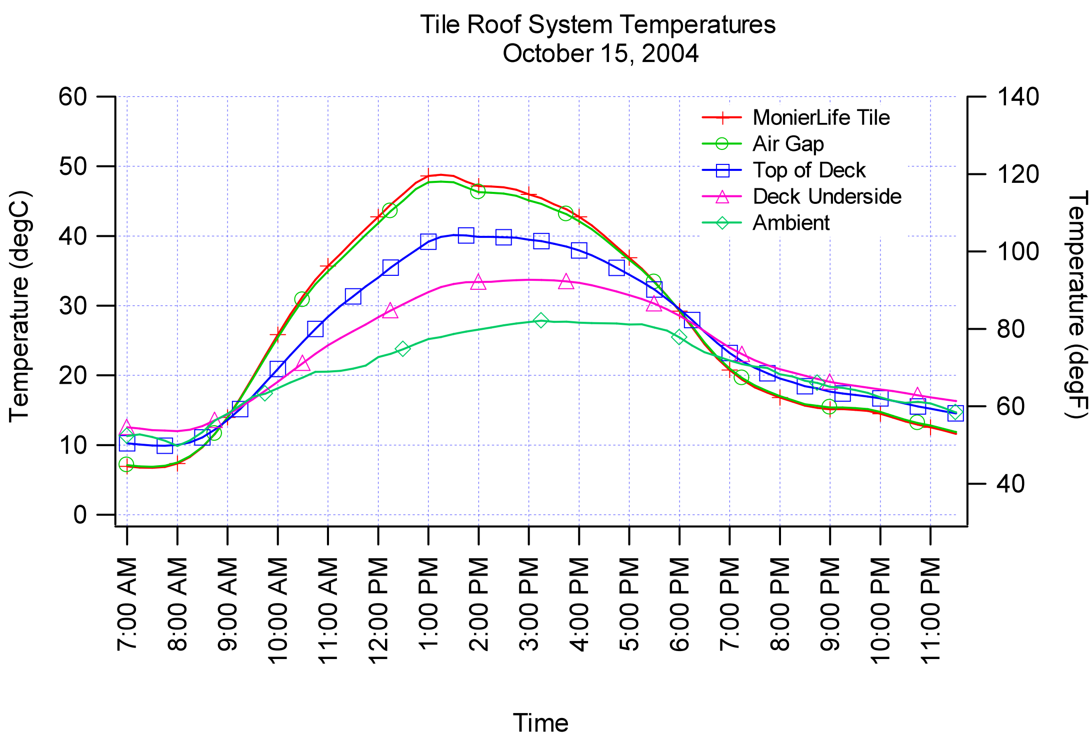

Figure 14: Temperature data from Location 3

Photo Credit: PowerLight Corporation

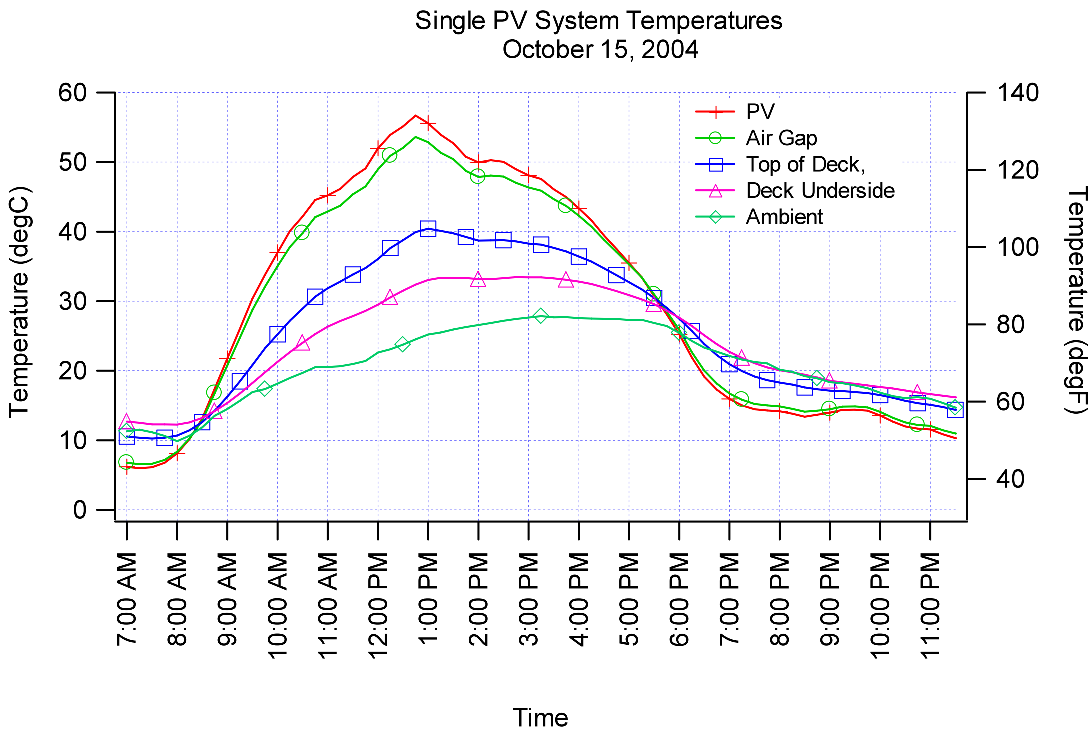

Figure 15: Temperature data from Location 7

Photo Credit: PowerLight Corporation

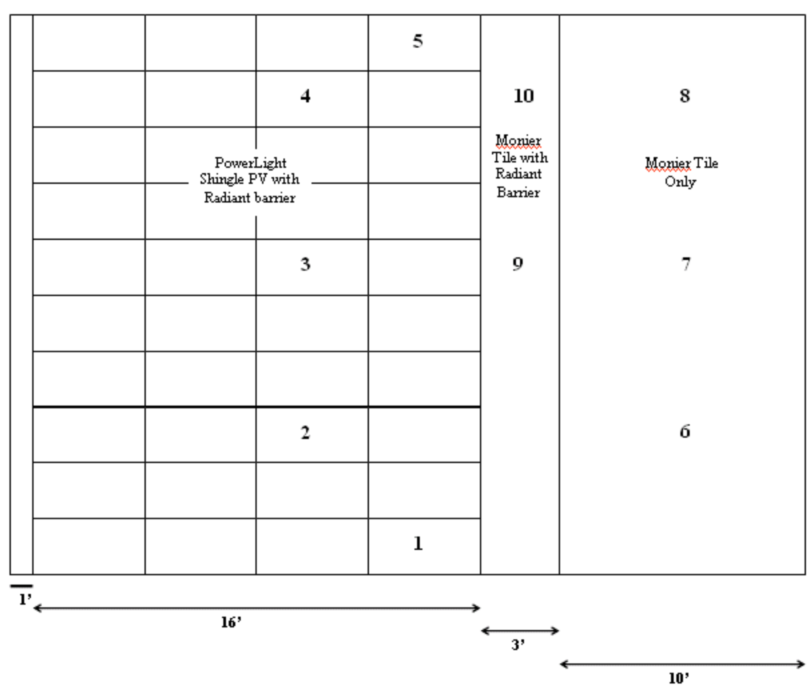

Figure 16: Thermocouple locations on demonstration array

Photo Credit: PowerLight Corporation

A comparison of the Shingle Tile temperature and the MonierLife tile temperature at these locations throughout the day is shown in Figure 17. Figure 18 shows the under-deck temperatures over the same period. While the PV modules reached a peak temperature 14°F greater than the MonierLife tiles (134°F vs. 120°F) the deck underside temperatures were nearly the same (within 0.5°F).

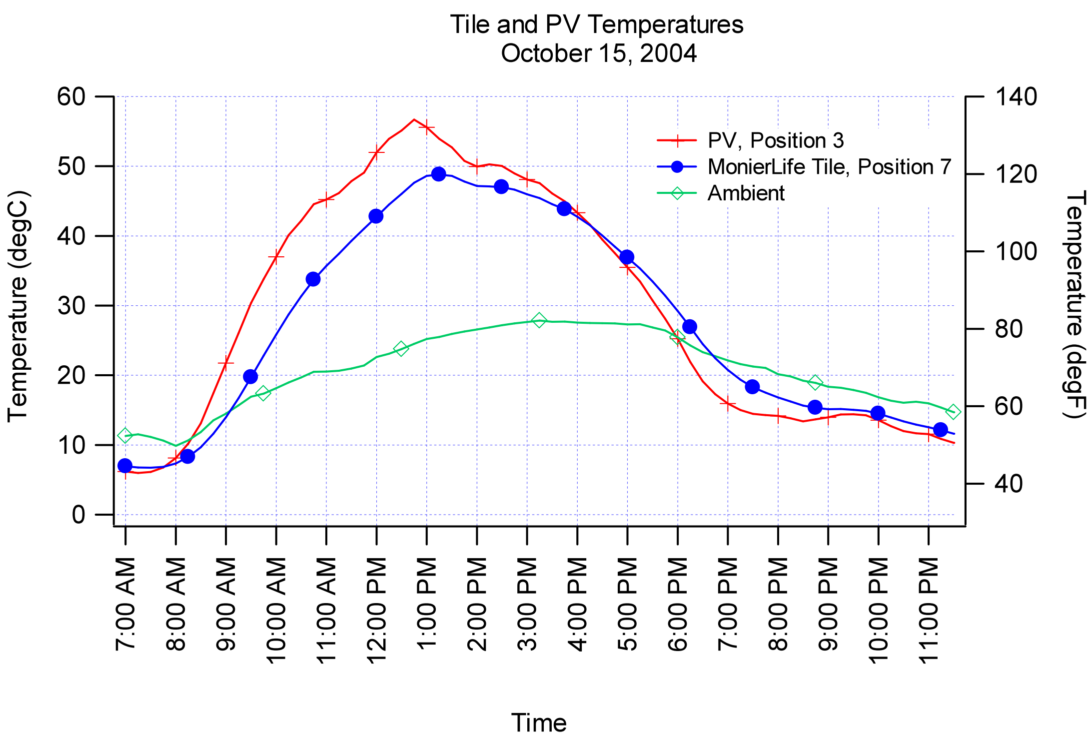

Figure 17: Temperature comparison of PV Tile (Location 3) with concrete tile (Location 7)
Photo Credit: PowerLight Corporation

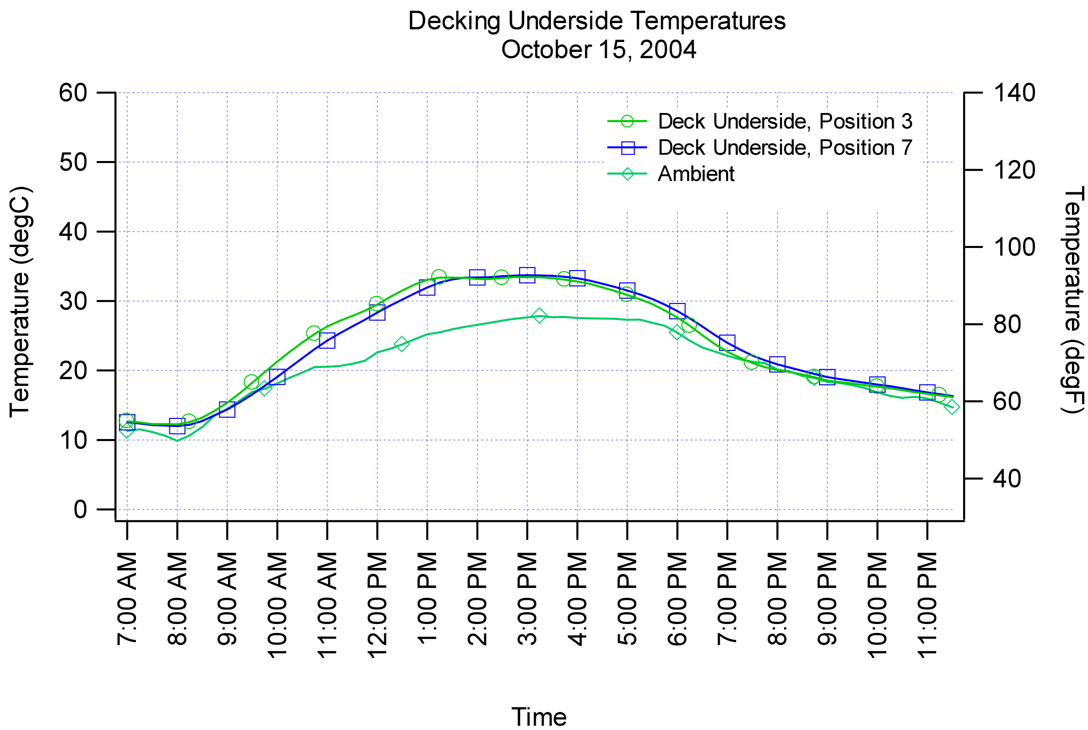

Figure 18: Under-deck temperatures below PV tile (Location 3) and concrete tile (Location 7)

Photo Credit: PowerLight Corporation

The similarity of the deck underside temperatures is significant because this surface is the interface where the heat transfers from the roof to the attic. As the temperature of the deck underside increases so does the transfer of heat to the building. Figure 18 shows that the transfer of heat from the deck under the Shingle Tiles and the MonierLife tiles is almost equivalent, even though the Shingle tiles are hotter.

Figure 19 shows the internal attic temperatures. This graph shows that the temperature of the attic under the Shingle Tiles and the temperature of the attic under the MonierLife tile were practically the same throughout the day. At their greatest variance, they are only 1.4°F apart. When these temperatures are similar to each other, the heat flux through each of the systems can be easily compared. Large differences in attic temperatures would make the difference in heat flux difficult to measure.

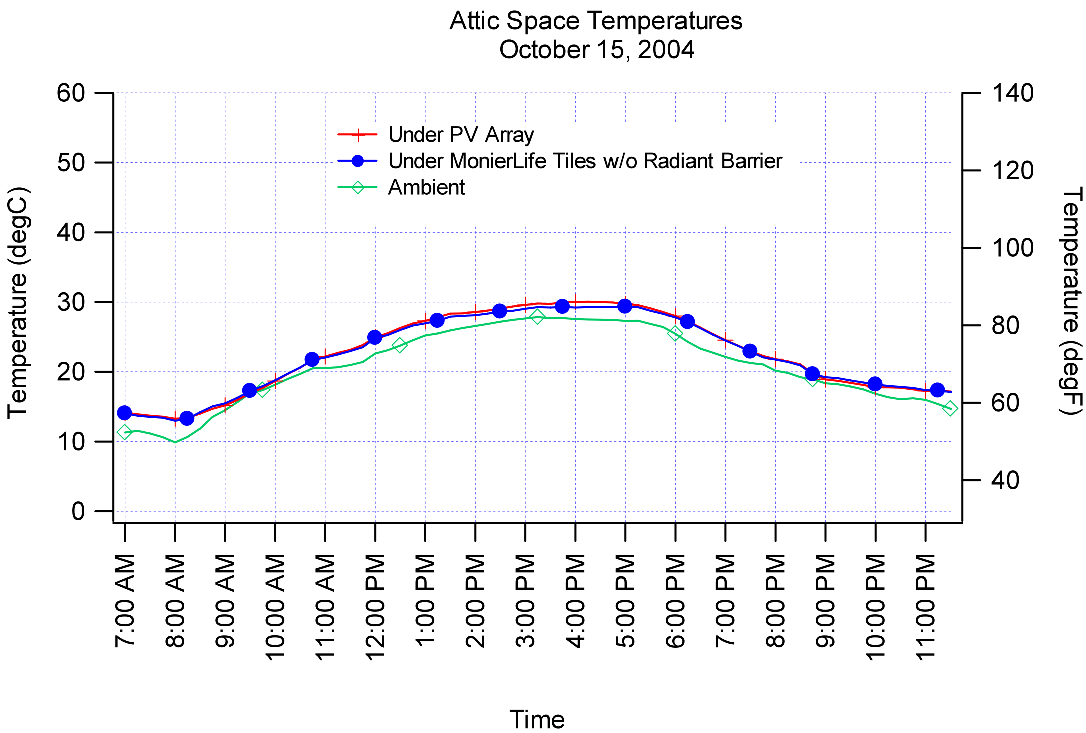

Figure 19: Internal attic temperatures

Photo Credit: PowerLight Corporation

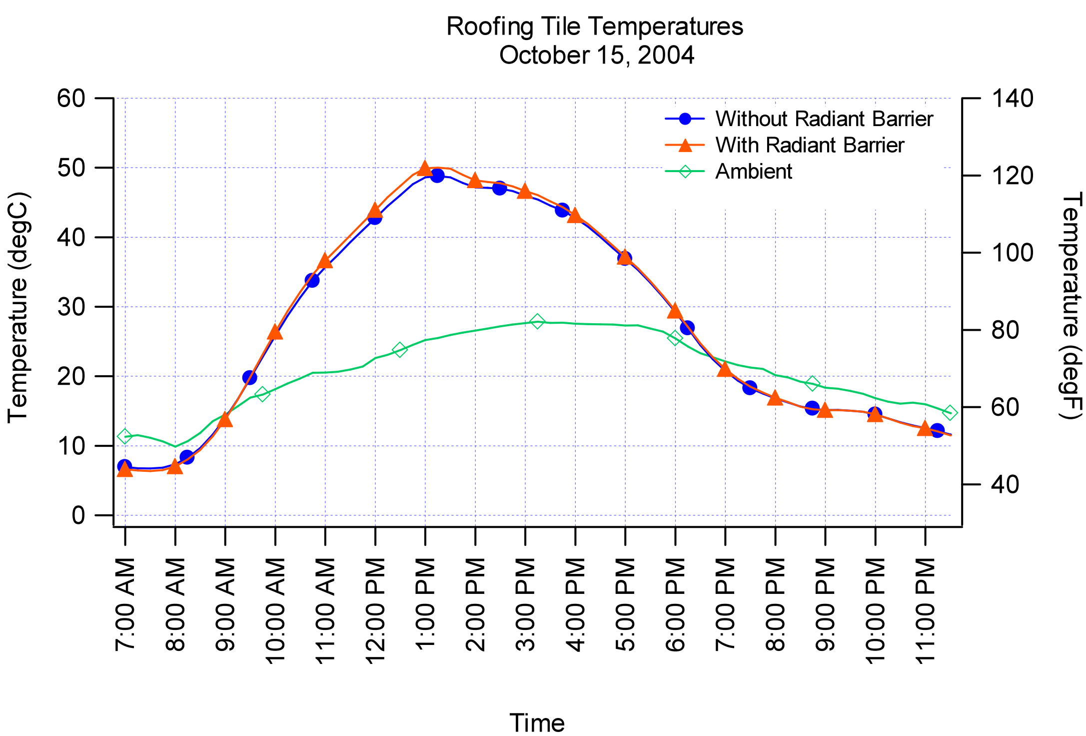

Figure 20: MonierLife Tiles with and without radiant barrier

Photo Credit: PowerLight Corporation

An additional comparison of the system temperatures for the two sections of MonierLife tiles was made to determine the effect of the radiant barrier. Figure 20 shows the recorded temperatures of the MonierLife tiles throughout the day. Temperature differences between the two sections were very small. The MonierLife tile with the radiant barrier exhibited a slightly higher temperature during mid-day than the section without the radiant barrier. Under the roof deck, the temperature was slightly lower for the section with the radiant barrier than the one without. Additionally, when comparing the two sections, Figure 21 shows that the deck under the MonierLife tile with the radiant barrier ran hotter in the middle of the day, but cooler at other times.

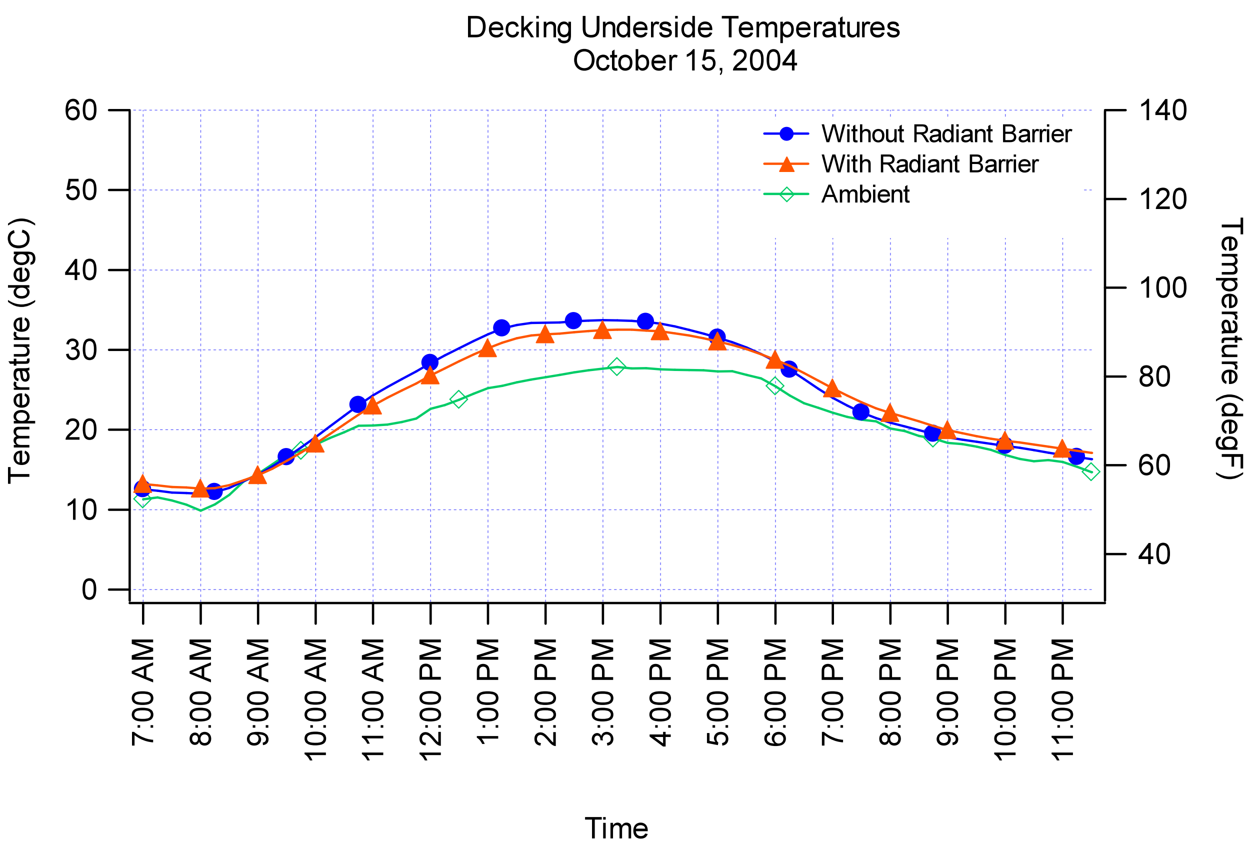

Figure 21: Under-deck temperatures of MonierLife Tiles with and without radiant barrier
Photo Credit: PowerLight Corporation

1.13 Cost

The cost of this product has not yet reached the goals outlined at the beginning of this product. During the development process, PowerLight has gained much knowledge about the market and the design constraints. The benefit of a class-A fire rating was not understood at the start. This fire rating will help streamline permitting processes for installations as well as provide an added level of consumer comfort with the product. Even though this adds cost, it is viewed as an important feature.

The thermal benefits provided by this product are an important aspect for optimizing the return on investment for potential customers and for market differentiation of the product. It is not difficult to design a tile, which includes a vented cavity that allows cooling air to flow behind the PV module. However, it becomes a difficult challenge to include a vented cavity while preventing the spread of flame in a fire test or preventing ingress of water during a hurricane. These constraints add much complexity to the design. These are lessons that have been learned in the most recent phase of the development process. At present, PowerLight views the benefits provided by the radiant barrier and the vented cavity as sufficient to justify the added complexity. In the latest version of the tile, a metal fire pan has been included, which helps direct the airflow, provides the benefit of the radiant barrier, and also provides the fire protection necessary to achieve a Class A fire rating. Now that a product has been developed that is ready to go to market, it will be an ongoing challenge to reduce the cost to make sure that the product is competitive in the market.

The assembly process has largely met expectations. During early pilot runs, the assembly required less than ten person-minutes per tile, which was the target. Some of the additional parts required for the Class A fire rating will add a small amount of assembly time, but this can then be lowered significantly through improved tooling as the production level grows.

Cost of PV laminates is also higher than anticipated at the start of this project. During the three-year duration, the cost of laminates has come down, but recent shortages have caused prices to rise again. This can change the acceptable cost level for the other components of the tile.

The cost of the first batches of tiles has been quite high due to the small number of units produced. PowerLight has received large volume quotes for parts that will provide a competitive tile cost through some investment in fabrication tooling. PowerLight is currently evaluating the appropriate level of tooling investment that will achieve the lowest overall cost.

1.14 Lessons Learned

Through this development process, PowerLight has learned much from interaction with building industry representatives in the residential market. It is important to provide an easy-to-install, cost-effective, complete package, including inverter, combiner boxes, transformers, PV roof tiles, and any other ancillary components. Developers also want assurances of good customer support, particularly during the installation of their first several jobs. The absence of a need to ground each tile is important as well as the ability to change out a damaged module without disassembling the entire array. Aesthetics are also very important. Designs that blend well with the surrounding roofing material are essential.

PowerLight was very pleased to receive feedback suggesting that its product will score well on all of these issues, indicating a highly marketable product.

1.14.1 Residential Markets

The residential market is divided between sloped roof and flat roof buildings. It is important to pursue both of these markets to provide maximum proliferation of PV products. The flat roof market is relatively untapped. There are many products offered for the sloped roof market, but the product developed during this project has addressed some of the shortcomings of these existing products. PV efficiency is increased. Heat transfer to the building, in comparison to other PV roof products, is decreased. Installation processes are improved, and the replacement of any broken modules has been made much simpler. Figure 22 shows the installation of product on actual residential roof.

Figure 22: Installation of product on residential roof

Photo Credit: PowerLight Corporation

1.14.2 Product Development

PowerLight is proud of the success that has been achieved in this product development project. It has resulted in a product that meets the goals of the Sacramento Municipal Utility District (SMUD) and the Energy Commission for reducing the cost of renewable energy and providing products for California's consumers that will help expand the use of renewables and distributed generation.

1.14.3 Commercialization Potential

It is clear that the product developed during this project is marketable and cost-effective. PowerLight is moving forward with commercialization of this product. The PowerLight sales team is working on several large projects for installation in 2005 and 2006. At the time of this report, PowerLight has already sold their first project using this new product. This project, consisting of many arrays on new houses in California, is expected to be installed later in 2005.

1.15 Continued Focus

1.15.1 Electrical Performance

It is important to maximize electrical performance of the tile. The production of electricity is the primary function of the system, so it must be given the highest priority. The tile design must evolve continuously to maximize the electrical output. This includes looking for ways to increase the cooling effects of the vented cavity design to maximize the efficiency of the PV cells. It also includes working with industry partners to adapt new cell technology to the tile as it becomes available.

1.15.2 Thermal performance

The most important issue with respect to thermal performance is the optimization of the PV module performance. The cooler the module is, the more efficiently it will operate. As such, it is important to continue looking for ways to improve airflow through the vented cavity. Now that a design has been developed that will provide cooling as well as fire protection, the design should be iterated to optimize the airflow.

The secondary benefit of the tile is the reduction in heat flow into the attic space below the array. This benefit can be measured and evaluated in terms of energy savings, but it remains to be seen how much value potential customers actually associate with it. The inclusion of a radiant barrier under the PV array is likely to be included in all systems since the fire pan is an integral part of the tile design. Current test results of the benefit of a radiant barrier under the concrete roofing tiles provided inconclusive results. This may be due to the small roof area dedicated to this comparison. A larger scale comparison would provide a better evaluation of the benefit of putting a radiant barrier over the entire roof surface.

1.15.3 Cost

Cost reduction will remain a high priority for all types of PV systems until they can compete with other forms of electricity production without buydown programs. It is a top priority for PowerLight to look continuously for ways to reduce the cost of this product as well as all of the others offered by the company. All aspects of the tile must be examined on a periodic basis for ways to reduce the cost of materials, labor, and overhead.

2. Gen II Insulated Tile for Flat Roofs

2.1 Introduction, Background and Overview

2.1.1 Problem Statement:

This project was undertaken to develop a new residential PV roofing product, designed for both retrofit and BIPV applications, which meets the California Energy Commission goal of affordability. In the process of carrying out this project, PowerLight embarked on market research to gain an understanding of the residential market for PV systems. The results of this research showed that in addition to the market for installing PV systems on sloped-roof residential houses, there was also a largely untapped market for PV on multi-unit, flat roof, residential buildings. Based on this finding, the scope of this project was expanded to include improvements to PowerLight's existing flat-roof product, PowerGuard and the development of a new version of PowerGuard, which uses a radiant barrier to achieve thermal benefits instead of PowerGuard's foam insulation.

This section of the report will describe the development of the second product in the project, the Gen II Insulated Tile for Flat Roofs.

An important step in the design process was to gain an understanding of the market requirements for a residential product. PowerLight did market research to understand the potential sales volume, customer requirements, and effective marketing methods. The results of this market research are discussed in Section 2.4.1 below.

2.1.2 Overview of Existing Products at Project Start

At the start of this project, PowerLight offered both roof- and ground-mounted PV systems for commercial applications. PowerLight has been manufacturing its flagship product, PowerGuard, in its Berkeley, California, factory since 1999.

PowerGuard building-integrated photovoltaic roofing tiles generate electricity from solar energy. A PowerGuard tile consists of a flat plate PV laminate mounted onto a flat, rigid, extruded polystyrene (XPS) board. Historically, the XPS boards have all been covered with a cementitious coating in what is now called Gen I PowerGuard. In the new Gen II version of PowerGuard developed as part of this contract, the XPS board is covered instead by a layer of sheet metal or plastic. Two edges of the XPS board are routed into a tongue profile and the other two edges are given a groove profile, allowing PowerGuard tiles to be assembled adjacent to each other in an interlocking fashion as shown in Figure 23 below. Adjacent tiles are tied together electrically through connectors supplied on each PV module, thus creating an electrical string of PV modules. One or more strings are then electrically connected in parallel at a remote location creating a solar electric array (PowerGuard system). The resulting DC current from the array is passed through a DC/AC inverter and isolation transformer before being tied into the building's electric distribution panel. PowerGuard tiles provide benefits in addition to the electricity produced in the form of added insulation and protection of the roof membrane from ultraviolet light. Figure 24 shows how a PowerGuard system can reduce the heat transfer into a building and reduce operating costs.

Figure 23: Installation of PowerGuard tiles
Photo Credit: PowerLight Corporation

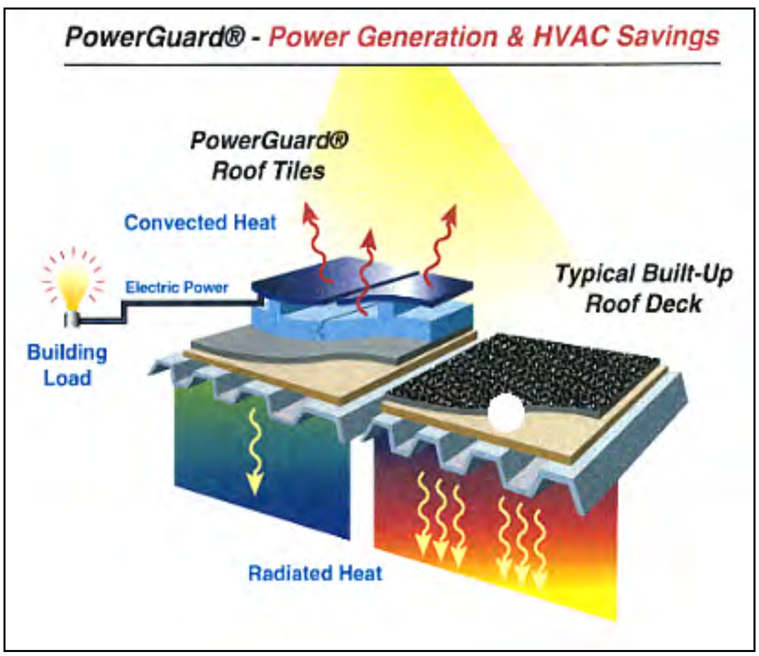

Figure 24: PowerGuard benefits
Photo Credit: PowerLight Corporation

2.2 Project Objectives

The original goal of this project was to produce a product designed for sloped roof residential buildings. As discussed in Section 2.1.1 above, the scope was expanded to include the development of two products designed for flat-roof, multi-unit residential buildings. At the time of this scope expansion, the goals for this product were described as follows:

- Derives its HVAC benefits to the roof from insulation, for both PV and non-PV tiles, which go around the PV array.
- Maintains PV cell temperature at relatively cool, “rack-mount” levels, unlike other direct–mounted building-integrated PV products.
- Certified by UL and ICC (formerly ICBO).
- Simple to install by one or two persons.
- Electrical wiring and interconnection will be integrated into the mounting system and are accessible after installation.
- Electricity and thermal performance that could obtain recognition by California Energy Commission Title 24.
- Has 30-year design life and increases roof durability.
- High volume manufacturing line at PowerLight will allow bulk purchases of the product.

2.3 Project Approach

PowerLight worked on two distinct configurations of this product. The first configuration has a PV module with a fixed slope of 10°, and the second has a PV module oriented horizontally. During the initial stages of this development effort, it was expected that the base for these two configurations would be the same, and that the only difference would be the support structure for the PV module and the size of the complete tile assembly. During the design process, however, the design of the two configurations diverged as described in the following sections.

2.4 Product Specification

The decision to install either a sloped PV module or a flat (horizontal) PV module is largely based on the size and orientation of the installation site and the requirements of the customer. A customer who is constrained with respect to how much area the PV array can take up, but who wants to maximize the capacity of the array is likely to use a flat PV configuration. A customer who has more space than necessary for the array or who wants to increase the amount of energy captured for each module may choose a sloped PV configuration. When the modules are sloped, they must be spread further apart to prevent shading of one row by the one adjacent to it. The distance between modules is defined by the ground cover ratio (GCR), which is the length of the module divided by the distance from one module to the next. The selection of GCR is a compromise between how much PV can be fit into a certain area and how much shading can be tolerated. A ground cover ratio is selected by modeling the annual energy capture of a system at different GCR’s and selecting the best one.

There is some compromise in selecting an optimal angle for a fixed slope product. At higher latitudes, a larger slope will be beneficial, but the distance between modules will increase, making the array larger. For this product, PowerLight wanted to choose an angle and a GCR that would provide maximum benefit for the majority of installation sites while keeping a reasonable size and cost for each tile. Shading loss needed to be kept to a maximum of 2% on an annual basis. As such, the optimum choices would have been 5° with 0.8 GCR, 10° with 0.7 GCR, or 15° with a 0.6 GCR. Cost increases as the tilt angle and separation distance increase, and wind performance will suffer as tilt angle increases for a fixed module size. A tilt of 10° was chosen as the most appealing compromise, providing reasonable increase in energy capture without too much increase in array size. Lowering the GCR beyond 0.7 was seen as too much of a restriction on array size. Once the angle had been selected, a full list of requirements was created for the tile design. This included design life, certification requirements, shipping and handling requirements, electrical specifications, and aesthetic requirements.

2.4.1 Discussion of Residential Markets and Roof Types

Size of the Market

PowerLight undertook research to better understand and measure the potential market for residential PV applications. This research covered the three primary geographical regions where PowerLight is currently active—the Pacific, Mid-Atlantic, and Mountain regions. A primary research objective was to compare the relative opportunities of flat roof applications (Gen II Insulated Tile for Flat Roofs and Gen II Radiant Barrier Tile for Flat Roofs) to sloped roof applications (Shingle Tile for Sloped Roofs). This was accomplished by noting the total square feet of installed flat and sloped residential roofs suitable for PV installation in each respective region. The table below summarizes these findings.

Table 1: Market analysis summary

	Million Sq Ft	GW
Pacific		
Flat	313	4.3
Sloped	214	3.0
Mid-Atlantic		
Flat	67	0.9
Sloped	82	1.1
Mountain		
Flat	192	2.7
Sloped	76	1.1
Totals		
Flat	572	8.0
Sloped	372	5.2

(GW, for Gigawatts, is an estimate of installed PV capacity for the respective roof areas)
(Source: NCRA baseline data, w/ PowerLight analysis, available for review)

As the data clearly indicates, the flat roofed residential space available for PV installation is one and one-half times that of the sloped roof space.

As further evidence of a potentially strong flat roof residential market, PowerLight has the following experience:

- An audit, recently conducted by a San Francisco solar power integrator showed that 75% of the single-family residences in their area have Flat roofs suitable for an average of 3 kW each.
- In the Northeast, PowerLight has sold a 50 kW system through a Massachusetts based integrator at an apartment complex with more than 25,000 square feet of roof space.
- PowerLight has sold a 100 kW PV system to a multi-tenant, residential complex in Santa Rosa, California, verifying the very real potential of this market.

Principal Considerations of Prospective Customers

Through PowerLight's extensive experience as an integrator of PV systems for flat roof applications, the company has acquired a considerable understanding of the market for such products. PowerLight has come to identify the factors that are most important to potential customers, what forms of marketing and customer service are most effective, and what generally drives and impedes the current market. Of particular interest for this report were the customers and markets for flat roof residential applications. For the most part, the interests of these customers were similar to those of customers looking at large-scale PV systems.

The primary customer motivation is economics, measured in return on investment. Financial returns between 10 and 20% are indicated as the hurdle rate, depending on individual customer requirements. Customers usually desire a full financial analysis be presented to them in order to evaluate the opportunity to purchase or lease a solar power system. Included in the analysis are tax benefits (e.g., Federal 10% Income Tax Credit, five-year accelerated depreciation), financial incentives if applicable (such as a rebate or buydown), electric bill savings from direct PV generation and HVAC savings (if applicable), loan payments (if applicable), and O&M costs.

Utility bill risk mitigation ("freezing" a portion of the electric bill) is another primary motivation. Secondarily, the owner can communicate to tenants the environmental benefits as a means to improve the "brand" of the building and as a "feel good" stewardship building management approach that enhances tenant goodwill.

The building owner is the target customer, such as owners of apartment buildings and other multi-family dwellings. Many of these projects are master-metered and the price of electricity is included in the rent. Therefore, the owner is highly motivated to reduce operating costs.

In terms of product design, providing products that yield a superior value proposition is the key driver. This is crucial in maintaining high levels of customer satisfaction and providing competitive advantage as well. Aesthetics are also very important in product design. Products that are elevated above parapet walls and are visible from the street are typically not favorable.

Impact to the roof and building structure is also an important consideration in product design. Products should be designed with close attention to the loading that they will impose on the building structure.

Secondary considerations are rather consistent among potential customers. They include:

- Company reputation
- Company track record
- Company longevity
- References
- Hands-on service
- Product quality
- Warranties

Marketing Efficacy

End customers found marketing to be a very important factor in the realization of projects. Referrals have been found to be the best marketing strategy in this market, yielding the most qualified leads.

Other praised marketing techniques include:

- Targeted direct marketing via direct mail
- Industry publications
- Cold calling
- Trade shows

Role of Value-Added Factors

Many end customers feel that it is difficult to distinguish between various PV products and systems, and so they look to value-added features as a source of differentiation. Considering that leaking roofs is one of the most frequent sources of building lawsuits, a feature that is of considerable value to customers is having the option of a system that does not require penetrations of the roof membrane. There are many savings to be realized by such a feature, such as lower installation and material costs, lower potential impact of the system to the integrity and water-tightness of the roof membrane, and a significantly reduced risk that the roofing manufacturer will void the warranty of the roof as a result of the system being installed.

Customers also assign considerable value to added insulation and/or shade which can be associated with a particular product. Incorporating roof insulation is a significant value-added feature for low-rise buildings, and is less significant for high-rise structures. In both cases, insulation is not as significant as a no-roof-penetration design and the roofing protection provided by a system.

Another feature that provides unquestionable value to customers is the ability to remotely monitor the performance of the system. Some customers access data remotely so that they can verify the system is performing to expectations. Further, they are able to determine the actual utility bill savings they are capturing with their system.

2.5 Development Process

The first step in the development process was to identify an appropriate material to cover the foam base of the tile. The original PowerGuard design uses a foam board with a tongue and groove profile around its edge and a cementitious coating on top, which protects the foam from ultraviolet (UV) radiation, strengthens and stiffens the foam board, and functions as the adhesive for the spacers that support the PV module. The main problem with the existing coating was its long curing time. It also had proven to be a difficult material to use as a base for the structure required to support the sloped PV module.

The sloped PV configuration was developed first. A variety of concept designs was created. The goal was to create a design that could be assembled easily in the factory with the PV module in a horizontal orientation. Once installed on a roof, the module was then to be raised to a sloped orientation using minimal tools and loose fasteners. As the design of the structure took shape, a variety of materials were evaluated for use in various parts of the design. Small-scale and full-scale test samples were made with various combinations of materials, and these were subjected to accelerated environmental conditioning and strength testing. Various configurations were sent to a corrosion test site to verify expectations of longevity in corrosive environments. The process and results of the structural design and material selection are discussed in section 2.6 below.

The sloped PV module requires a wind deflector on the North face. This wind deflector also needed to be assembled in a horizontal orientation and then fold out to the proper position once the tile was installed.

An important part of the wind deflector design was the optimization of the shape of the entire tile assembly using both computational fluid dynamics (CFD) modeling and wind tunnel testing. Data from CFD modeling and from small-scale and full-scale wind tunnel tests were used to fine-tune the design of the deflector to ensure that the tile would not move on the roof or get blown off.

Once the sloped tile design had been completed, work began adapting it to a tile with a horizontal PV module.

2.6 Product Development

2.6.1 Sloped Tile Development

The sloped PV configuration was developed first. The complete tile consists of a foam backerboard with a tongue and groove profile around the edge. A metal capsheet is laminated to the top of the backerboard as shown in Figure 25. The PV module is supported by a hinge, which allows the tile to ship with the PV module laid flat and then rotate into a sloped orientation once it is installed on the roof. The wind deflector supports the north side of the PV module. These parts are shown in Figure 26. The complete tile assembly is shown in Figure 27 in the orientation it will have once the PV module has been erected after installation on the roof.

Figure 25: Foam backerboard and metal capsheet

Photo Credit: PowerLight Corporation

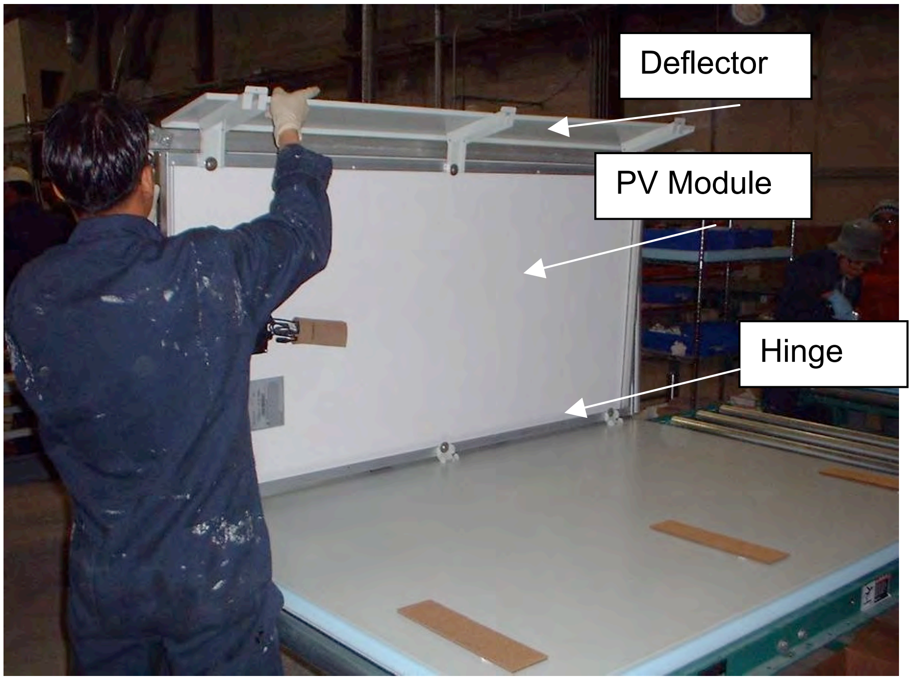

Figure 26: PV Module, hinges, and deflector panel
Photo Credit: PowerLight Corporation

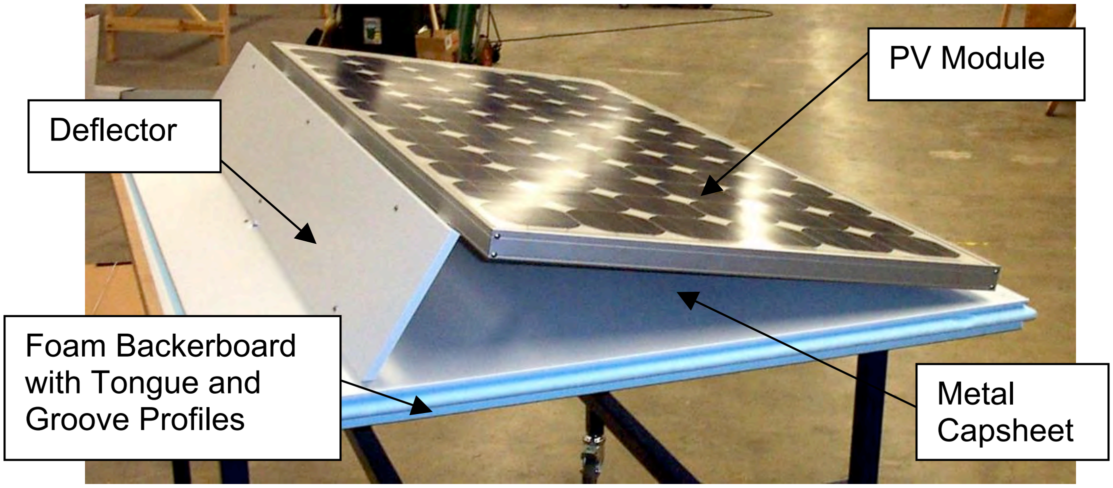

Figure 27: Completed Gen II insulated tile with sloped PV
Photo Credit: PowerLight Corporation

After investigating material options for replacing the cementitious coating, PowerLight decided to use 24-gauge galvalume coated steel. This material has been used in outdoor and roofing applications for many years, so it was deemed a good choice with respect to longevity. An additional coating was put on each side of the galvalume to provide the desired appearance on the top and to provide a suitable surface on the bottom to bond to the foam base.

Once the 24-gauge galvalume had been specified, the next step was to find an adhesive that would bond it to the foam backerboard. An extensive search was done along with a comprehensive testing program on the candidates that appeared to have the best chance of meeting the performance and cost goals. An adhesive was chosen and a search for dispensing equipment was initiated.

Along with the design of the backerboard assembly, the structure to support the PV module was developed. The structure was required to allow shipping of the PowerGuard tile with the PV module in a horizontal orientation and then provide a method for rotating the module into a 10° slope once it was installed at the jobsite. The hinge mechanism, which allowed for rotation of the PV module, went through several iterations. Early versions used a "living hinge," a metal piece designed to bend at the right point to provide proper positioning of the module. This design is shown in Figure 28. This design allowed for easy rotation, but did not provide accurate, consistent positioning of the PV module in the sloped position. The living hinge was abandoned in favor of a pair of rivets which would act as hinge pins as shown in Figure 29. This provided easy rotation and accurate positioning of the PV module.

Figure 28: Living hinge used on earlier design.
Photo Credit: PowerLight Corporation

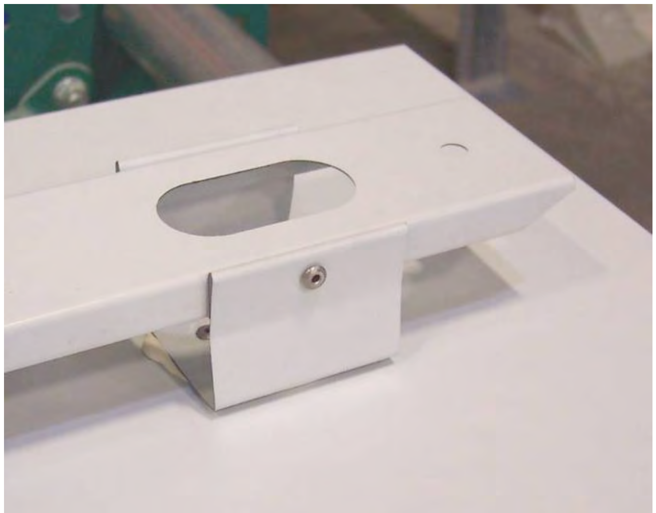

Figure 29: Hinge used on final design.
Photo Credit: PowerLight Corporation

It was advantageous to incorporate a walkway into the design of the tile, so the slope of the wind deflector was made such that a small section of the tile base was not covered by the deflector. In the early tile designs, the deflector was made so that it lay flat across this open part of the tile base during manufacturing and shipping as shown in Figure 30. Then it would be moved into its final orientation when the PV module was rotated to 10° as shown in Figure 31.

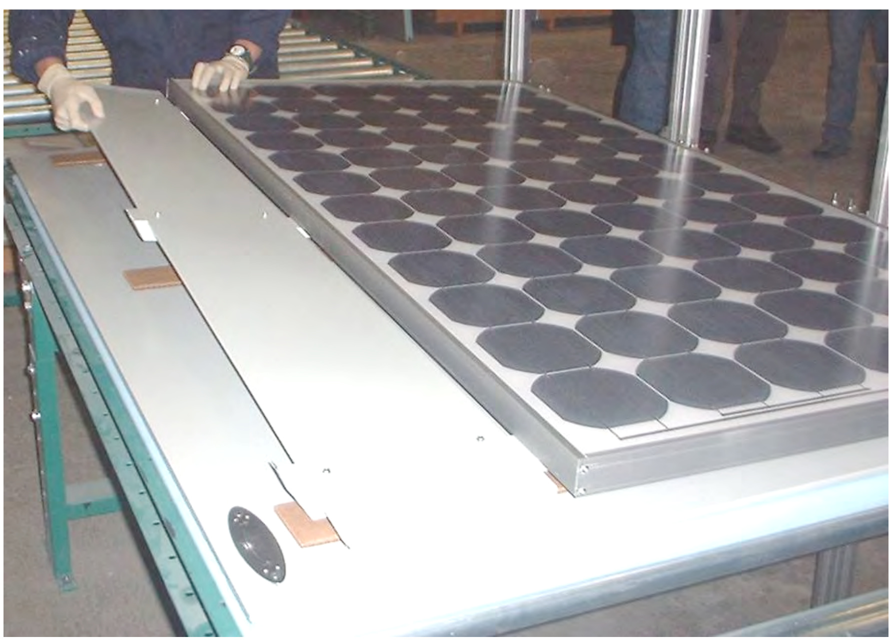

Figure 30: Earlier deflector design as assembled.
Photo Credit: PowerLight Corporation

Figure 31: Earlier deflector design installed.

Photo Credit: PowerLight Corporation

This design worked for manufacturing, though it was a bit awkward. For installation, however, the design of the deflector caused a large increase in the amount of time and labor required to complete the wiring of the array. The design was then changed so that the deflector was assembled folded underneath the PV module rather than next to it. This allowed all the wires to be run during installation with the PV modules sitting flat. After the wires were in place, the PV modules and deflectors could be easily popped into position. Figure 32 shows the later deflector design. Most of the tiles in the picture show the deflector as it is assembled and shipped, folded under the PV module. In the foreground, workers are erecting one of the PV modules and positioning the deflector.

Figure 32: Later deflector design.
Photo Credit: PowerLight Corporation

This was a big improvement for installation of the array, and at the same time, it improved the manufacturing process. The manufacturing improvements are discussed below in Section 2.8.

2.6.2 Flat Tile Development

During the process of developing the sloped tile design, the price of steel had risen significantly. The use of steel as a cap sheet material for the foam baseboard was no longer economically viable for the flat tile design. A search began for an alternate material that would meet the requirements of strength, fire resistance, and cost. Testing began on a variety of polymer materials. A small number of tiles were made as proof-of-concept prototypes using a capsheet material that had reliable adhesion characteristics, though it was not seen as a long-term solution due to its cost and lack of durability in commonly available thicknesses. The proof-of-concept prototypes were installed on the roof of PowerLight's Berkeley, California, factory.

Figure 33: Proof-of-concept prototypes Installed on PowerLight's factory
Photo Credit: PowerLight Corporation

The results of this small production run of proof-of-concept prototypes were encouraging. The tiles held up well during shipping tests and were easy to handle on the roof.

After this installation, the search continued for a long-term solution for the capsheet material. One material was chosen which satisfied the requirements. Fire testing had been carried out on small-scale samples, and they indicated that the material would provide the necessary fire protection. Plans were made to do a larger production run to make tiles for a demonstration array. Once the actual materials were received, some full-scale tiles were made, and fire testing was done on them. Unfortunately, the results from the full-scale tests were far worse than those from the small-scale tests. The decision was made to abandon the chosen material and resume the search for an alternative. A consultant from the University of California, Berkeley, was brought in to help with the selection. After an exhaustive search, it was determined that none of the candidates would meet both the performance requirements and the cost requirements. At this time, PowerLight made the decision to abandon the flat version of this product. For projects that warranted a flat product, the original PowerGuard tile design would be used, and the new design would be used only for projects that required a sloped PV module.

2.7 Final Product

2.7.1 Sloped Tile

During the months of February and March 2003, the first system was installed. The total system size was more than 300 kilowatt-peak (kWp). Figure 34 through Figure 39 show the system during and after installation:

Figure 34: Stacks of tiles after lifting to roof
Photo Credit: PowerLight Corporation

Figure 35: Tiles are erected by workers
Photo Credit: PowerLight Corporation

Figure 36: System in place awaiting curb installation
Photo Credit: PowerLight Corporation

Figure 37: Looking north over near-complete array
Photo Credit: PowerLight Corporation

Figure 38: Southwest corner of completed array
Photo Credit: PowerLight Corporation

Figure 39: Northwest corner of completed array
Photo Credit: PowerLight Corporation

In July 2003, a second system was installed incorporating improvements in deflector design and PV module mounting structure.

Figure 40: Final design tiles installed
Photo Credit: PowerLight Corporation

Figure 41: Completing array wiring
Photo Credit: PowerLight Corporation

Figure 42: Erecting PV modules
Photo Credit: PowerLight Corporation

Figure 43: Completed array
Photo Credit: PowerLight Corporation

2.7.2 Flat Tile

As described in Section 2.6.2 above, the search for a suitable capsheet material ended without a candidate that met both performance and cost requirements, and the development process was abandoned. The small proof-of-concept array is still in place on PowerLight's factory roof as shown in Figure 44, but there are no plans at this time to continue the development of a commercial product.

Figure 44: Completed flat tile array
Photo Credit: PowerLight Corporation

2.8 Manufacturing Process

In parallel with the product development, the manufacturing process was designed and implemented. The goal was to have a steady flow process, ensuring minimal accumulation of work-in-process (WIP), and incorporating error-proofing measures wherever possible to minimize rejects.

2.8.1 Sloped Tile

For the sloped PV tile, a production line was set up in PowerLight's Berkeley factory. The production line was set up to allow a throughput of two minutes per tile. Production started in January 2003. The new production process proved to be very controllable from the outset, and within the second week of production, the workers were making their target of 180 tiles per shift. Additionally, overall quality was very good, with a reject rate of only 0.3%.

The WIP inventory and the raw material inventory feeding into the line are kept to a minimum using *kanbans*. PowerLight incorporated error proofing into the manufacturing process. As much as possible, the various parts were designed so that they will only fit together the right way. Some parts were modified to include alignment features that could be added with minimal cost impact. Changes like these help to insure a high yield from the manufacturing process.

PowerLight has a supply chain set up for the Gen II insulated tile. The supply chain includes PowerLight qualified vendors for all of its components. In addition, a supplier corrective/preventive action program has been implemented as part of the quality system. Regular vendor site audits have been performed.

After the first large production run, the tile design was modified based on lessons learned during early production and during the installation of the first large array. The changes to the design of the deflector were described above in Section 2.6. Changes to the deflector and to the support structure improved the manufacturing process. The attachment of the PV module for the earlier tile design had to be done with the module held vertically to provide access to the fasteners as shown in Figure 26. In the later design, the shape of the hinges, PV mounting brackets, and deflectors were changed so that the PV module could be attached in a horizontal position as shown in Figure 45. This made the assembly of the tile easier, safer, and faster. Modifications to the PV mounting brackets incorporated some alignment features, making it nearly impossible to assemble in the wrong way.

Figure 45: PV attach process, July production
Photo Credit: PowerLight Corporation

2.8.2 Flat Tile

PowerLight set up pilot production equipment for the Insulated Tile with flat PV in the Berkeley factory. The flow of materials was not optimized for pilot runs, but *kanbans* were sized and set up for production.

Initial pilot production was done, showing the viability of the manufacturing process. Capsheet material was dispensed from rolls and laminated to the foam boards. The tongue and groove profiles were then machined into the edges of the lamination using the CNC routers. Spaces were machined out of the capsheet material to provide mounting positions for the spacers. These completed baseboards were then moved to the PV attachment station where adhesive was laid down followed by positioning of the PV modules. Photographs of this process are shown in Section 2.9.2 below.

2.9 Production Data and Photos

2.9.1 Sloped Tile

The following photographs show the manufacturing line and process for the Gen II Insulated Tile for Flat Roof with sloped PV module. These pictures show the final iteration of the design and manufacturing process.

Figure 46: Adhesive application

Photo Credit: PowerLight Corporation

Figure 47: Spacer assembly

Photo Credit: PowerLight Corporation

Figure 48: Deflector assembly
Photo Credit: PowerLight Corporation

Figure 49: Attachment of deflector assembly to backerboard
Photo Credit: PowerLight Corporation

Figure 50: Positioning of PV module
Photo Credit: PowerLight Corporation

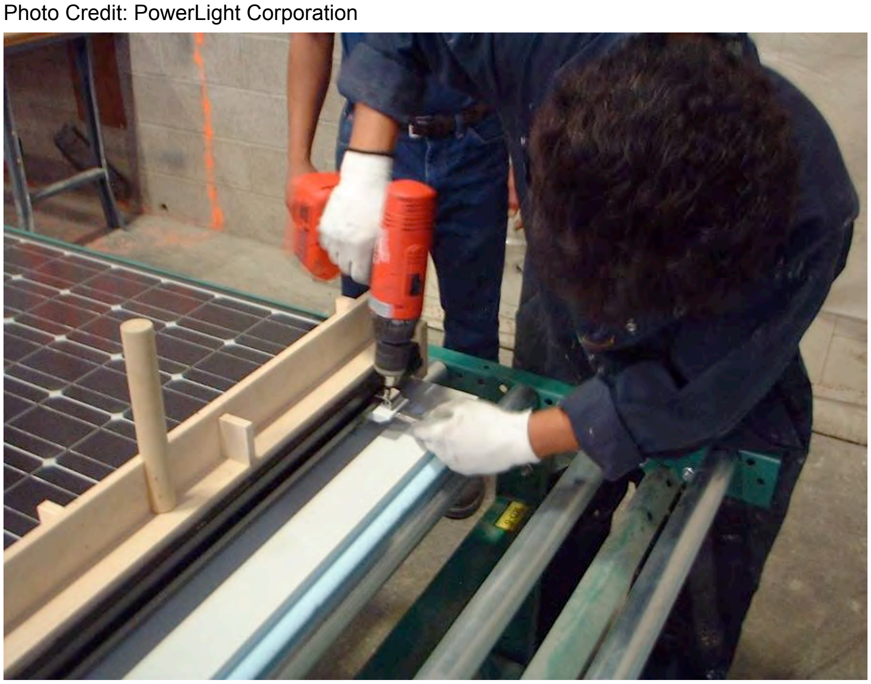

Figure 51: PV module fasteners
Photo Credit: PowerLight Corporation

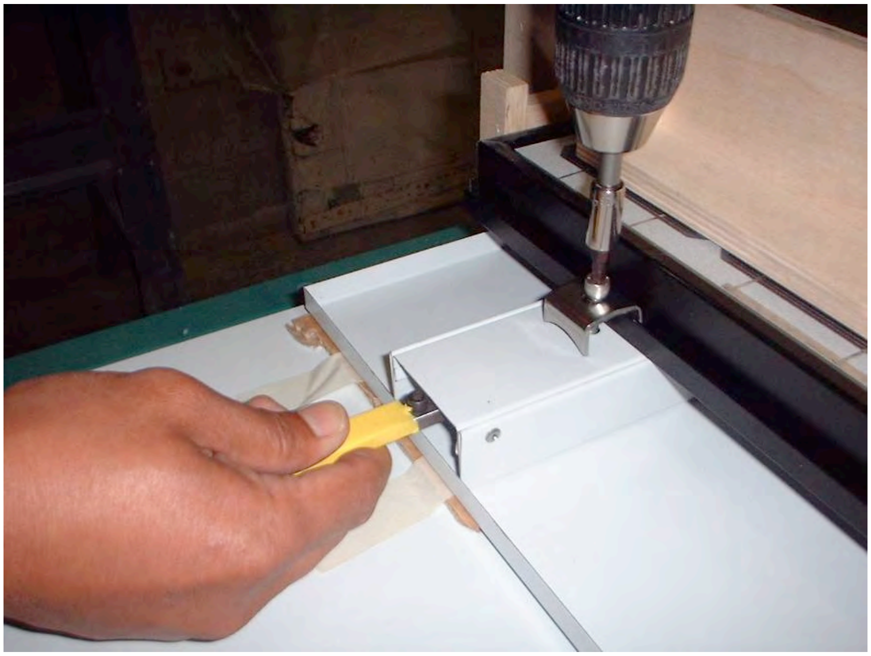

Figure 52: PV Module fasteners
Photo Credit: PowerLight Corporation

Figure 53: Completed tile
Photo Credit: PowerLight Corporation

2.9.2 Flat Tile

The following photographs show the assembly process for the Insulated Tile for flat roof with a horizontal PV module as it was set up in PowerLight's Berkeley facility.

Figure 54: Adhesive application and QC check
Photo Credit: PowerLight Corporation

Figure 55: Capsheet dispensing fixture
Photo Credit: PowerLight Corporation

Figure 56: Capsheet lamination
Photo Credit: PowerLight Corporation

Figure 57: Capsheet lamination
Photo Credit: PowerLight Corporation

Figure 58: PV Module attachment
Photo Credit: PowerLight Corporation

Figure 59: Completed tile
Photo Credit: PowerLight Corporation

2.10 Certifications

The final design incorporated the use of framed PV modules. Each of these modules carries a UL listing independent of the mounting method. The primary reason to have a UL listing on this type of product is to provide assurance to the customer and building inspector that the installed array will be safe, and to qualify the installation for rebates offered for the installation of PV systems. For the most part, the UL listing of the module is sufficient to satisfy these needs.

The UL listing of the PV modules along with the use of standard grounding methods is sufficient to satisfy building inspectors that the array will be electrically safeguarded.

ICC certification has been applied for, and the design is being evaluated.

2.11 Electrical Performance

PowerLight is monitoring the electrical performance of the first large array of the Gen II Insulated Tile for Flat Roof with sloped PV modules. Figure 60 shows the comparison of expected energy output based on the actual measured weather conditions with actual measured energy output of the system. Overall, the system is putting out more energy than expected, with a cumulative performance index of 108%. This verifies the efficacy of the design in fulfilling its primary goal of capturing energy and turning it into electricity.

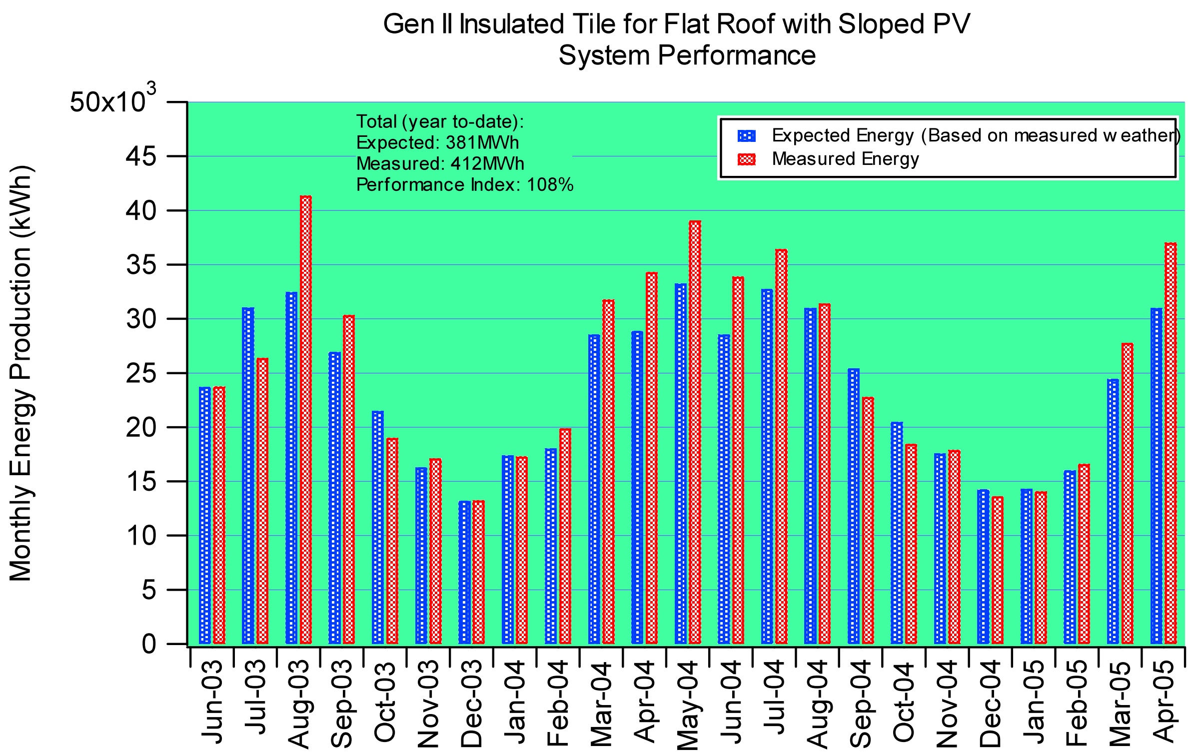

Figure 60: Electrical performance of Gen II Insulated Tile for Flat Roof system

Photo Credit: PowerLight Corporation

2.12 Thermal Performance

A large-scale commercial system was installed in 2003 using the sloped PV version of the Gen II Insulated Tile for Flat Roof. This system was used to validate the manufacturing and installation processes for the tile design. PowerLight was unable to install thermal monitoring equipment on this system. PowerLight's plan was to install thermal measurement instrumentation at another commercial installation during the third year of the project when the flat PV version of the product was ready. Unfortunately, when the decision was made to abandon the flat version of the product, there were no other prospective installations for the sloped version that would have allowed for the collection of thermal data in the time frame of the contract.

Thermal measurements had been made on a small prototype system installed at FSEC. While this was early in the development process, the portions of the design that would affect thermal performance were unchanged in the final product, so the results are applicable to the final product. The stated objective for the test by FSEC was "to evaluate the thermal performance and estimate the potential for reduction in cooling energy use for a building." Two versions of the insulated tile were tested: with and without a radiant barrier. A section of roof was also included as a control in the study. Thermocouples were used to measure the back of the PV module, the airspace behind the PV module, the outer surface of the PowerGuard backerboard, and the roof surface under the tiles. Other sensors installed to measure ambient temperature, control roof surface temperature, solar irradiance, and wind speed.

The results of this test show that the PV modules operate near the temperature of the control section of the roof, but the roof surface beneath the tiles is 70°F cooler at maximum irradiance.

The study found that "roof surface temperatures for the sloped PowerGuard remain very close to the ambient temperature. This indicates that a building with the sloped PowerGuard system installed over the entire roof would have very little heat flux into the building that could be attributed to direct solar gain." The study quantified this benefit by calculating that for 1000 ft^2 of roof, "The net difference in heat flux is 110,715 BTU/day of a load reduction of approximately 15kWh/day per 1,000 ft^2 of roof area."

2.13 Cost

While the sloped PV version of this product has been launched in the market, the cost is still higher than the goals set out at the beginning of this project. A jump in the cost of steel that occurred about halfway through this project made it difficult to meet cost goals. The product remains viable in some situations when the customer has a large roof area and can gain some benefit from the additional insulation value. When the customer's array is limited by roof size, higher capacity can be achieved from a flat PV module. As discussed above, the flat PV version of this product could not be made economically viable, and it has been abandoned. PowerLight continues to offer this product for certain customers, but increasingly, those customers are interested in the Gen II Radiant Barrier Tile for Flat Roofs due to its lower cost. The Gen II Radiant Barrier Tile for Flat Roofs is discussed in detail starting in Section 0 below.

2.13.1 Residential Markets

The residential market is divided between sloped roof and flat roof buildings. It is important to pursue both of these markets to provide maximum proliferation of PV products. The flat roof market is relatively untapped. There are many products offered for the sloped roof market, but the product developed during this project has addressed some of the shortcomings of these existing products. PV efficiency is increased. Heat transfer to the building is decreased. Installation processes are improved, and the replacement of any broken modules has been made much simpler.

2.13.2 Commercialization Potential

PowerLight has sold and installed two large commercial projects with the Gen II Insulated Tile for Flat Roofs with sloped PV modules. At the start of this development effort, it was anticipated that the version of this product with flat PV modules would also be launched in the market as well, but problems with cost and fire rating have caused PowerLight to abandon that portion of the development effort. The original PowerGuard tile design will continue to be sold for projects that will use a horizontal PV module.

2.14 Continued Focus

2.14.1 Electrical Performance

It is important to maximize electrical performance of the tile. The production of electricity is the primary function of the system, so it must be given the highest priority. It can be seen from the electrical performance results that the tiles are performing as expected. Nevertheless, it is vital to work continuously toward improved electrical output of PV systems. This is necessary to the continuous improvement of the cost of energy from PV.

2.14.2 Thermal Performance

The electrical performance results show that the PV operating temperature is in the range that was expected. The other aspect of the thermal performance is the amount of heat flowing into the building. PowerLight has many years of experience with insulated PowerGuard tiles, and the thermal benefits are well documented. The value of this benefit is different for different customers, depending on the type and age of the building on which the product is being installed. While the insulation value of the PowerGuard product will continue to make it a desirable product, it is not clear at this time that there is a need to improve the thermal performance. PowerLight is not expecting to look for ways to improve this aspect of PowerGuard tiles. Cost reduction is seen as a much more important path at this time.

2.14.3 Cost

Cost reduction will remain a high priority for all types of PV systems until they can compete with other forms of electricity production without buydown programs. It is a top priority for PowerLight to look continuously for ways to reduce the cost of this product as well as all of the others offered by the company. All aspects of the tile must be examined on a periodic basis for ways to reduce the cost of materials, labor, and overhead.

3. Gen II Radiant Barrier Tile for Flat Roof

3.1 Introduction, Background, and Overview

3.1.1 Problem Statement

This project was undertaken to develop a new residential PV roofing product, designed for both retrofit and BIPV applications, which meets the California Energy Commission goal of affordability. In the process of carrying out this project, PowerLight embarked on market research to gain an understanding of the residential market for PV systems. The results of this research showed that in addition to the market for installing PV systems on sloped-roof residential houses, there was also a largely untapped market for PV on multi-unit, flat roof, residential buildings. Based on this finding, the scope of this project was expanded to include improvements to PowerLight's existing flat-roof product, PowerGuard and the development of a new version of PowerGuard, which uses a radiant barrier to achieve thermal benefits instead of PowerGuard's foam insulation.

This section of the report will describe the development of the third product in the above list: the Gen II Radiant Barrier Tile for Flat Roofs.

An important step in the design process was to gain an understanding of the market requirements for a residential product. PowerLight did market research to understand the potential sales volume, customer requirements, and effective marketing methods. The results of this market research are discussed in Section 2.4.1 above.

3.1.1 Overview of Existing Products at Project Start

At the start of this project, PowerLight offered both roof and ground mounted PV systems for commercial applications. PowerLight has been manufacturing its flagship product, PowerGuard, in its Berkeley factory since 1999.

PowerLight had done research on the efficacy of radiant barriers to prevent the transfer of heat into the roof of a building. Prototypes had been made in various forms using PowerGuard tiles, and these had been installed on roofs and in test labs. Thermal data indicated that the presence of a radiant barrier was effective in significantly reducing the heat flow into the building. Some concept designs had been made for tiles without foam insulation, but no prototypes had been constructed.

3.2 Project Objectives

The original goal of this project was to produce a product designed for sloped roof residential buildings. As discussed in Section 0 above, the scope was expanded to include the development of two products designed for flat-roof, multi-unit residential buildings. At the time of this scope expansion, the goals for this product were described as follows:

1. Derives its hvac benefits to the roof from radiant barrier, for both pv and non-pv tiles, which go around the pv array.

2. Designed to accommodate a greater number of roof penetrations (e.g. Building vents) than gen ii insulated tile.
3. Designed for lower cost relative to gen ii insulated.
4. Installs without the use of penetrations through the roof membrane.
5. Maintains pv cell temperature at relatively cool, "rack-mount" levels, unlike other direct–mounted building-integrated pv products.
6. Certified by ul and icc (formerly icbo).
7. Simple to install by one or two persons.
8. Electrical wiring and interconnection will be integrated into the mounting system and are accessible after installation.
9. Has 30-year design life and increases roof durability.

3.3 Project Approach

The Gen II Radiant Barrier Tile was designed for installation on flat roofs without the use of penetrations through the roof membrane or ballast. It is meant as a lower cost of energy alternative to the Gen II Insulated Tile while still reducing heat transfer into the building through the use of a radiant barrier. The product has been designed to be assembled quickly and easily on the roof at the job site. Loose fasteners and tools required are minimized. PV modules are mounted at a 10° slope, and a walkway is provided between each row.

3.4 Product Specification

The specifications for the Gen II Radiant Barrier Tile for Flat Roofs are similar to those for the Gen II Insulated Tile, but replacing the foam insulation with a radiant barrier to reduce the heat transfer into the building. It was important that the Radiant Barrier product be easy to install and require no penetrations through the roof membrane to secure it on the building. The design had to be compatible with PV modules from a variety of suppliers, and it had to assemble with a minimum of tools and loose fasteners. All exposed metal parts needed to be grounded.

3.5 Development Process

At the beginning of this development effort, two different concepts were developed. The first concept was called the field assembly design. It was designed with the intention that all of the parts would be fabricated and sent directly to the installation site, to be assembled on the roof. This design is shown in Figure 61 below.

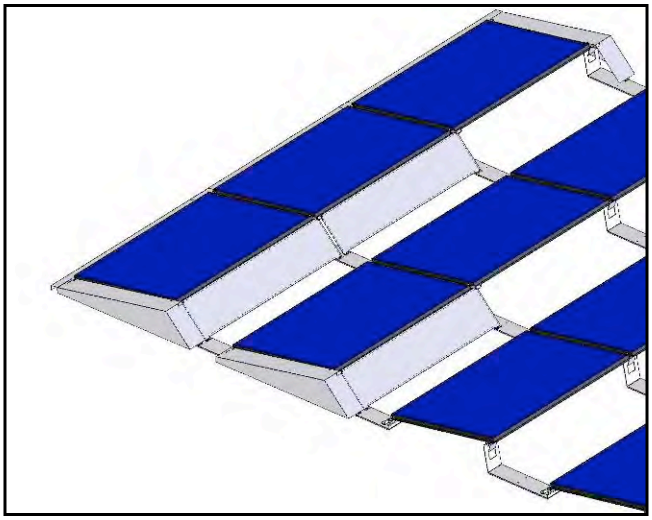

Figure 61: Field assembly design.
Photo Credit: PowerLight Corporation

The second concept, dubbed the fold-out design, was designed to be assembled in a factory using support structure that could be folded up for high shipping density and then unfolded during installation at the job site. This concept is shown in Figure 62.

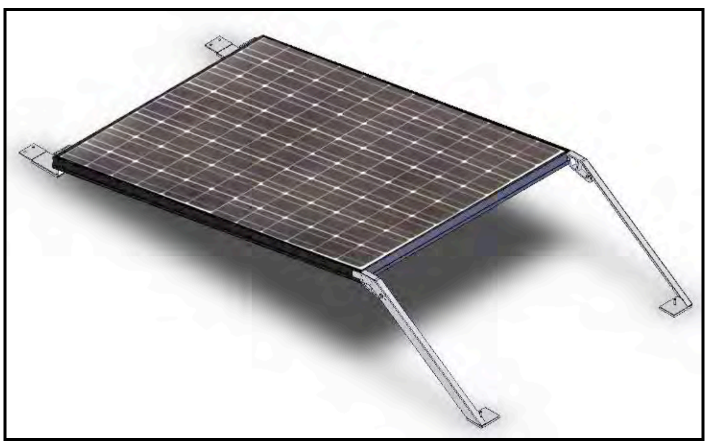

Figure 62: Fold-out design.
Photo Credit: PowerLight Corporation

A design review was held with these two designs and feedback was received from engineers, company executives, installers, and sales people. The consensus was that the field assembly design was the preferred one. It was likely to have lower cost, and it was not expected to significantly increase the installation labor over the fold-out design.

At this point, the fold-out design was abandoned, and work began on designing prototype parts for the field assembly design. The initial focus was on the design of the support leg. The early designs were for an extruded aluminum part with small inserts that could be chosen based on the type of PV module being used. The extrusion proved to be an unsatisfactory solution, so the final design uses a stamped sheet metal piece. A soft material is put on the bottom of each leg to prevent the metal leg from sitting directly on the roof membrane.

As with the Insulated Tile for flat roof with a sloped PV module, it was necessary to include wind deflectors on the North face of each PV module. The design of the wind deflector proved difficult due to the competing constraints of cost and required rigidity. The final design was tested in a wind tunnel to ensure that the deflector did not vibrate or permanently deform during high or turbulent wind.

One of the design constraints was to keep fasteners and tools to a minimum. The use of swaged studs installed in the sheet metal foot eliminated loose bolts. A clamp style mount was also designed to double as a grounding connector. This worked well and reduced the number of parts.

3.6 Product Development

Once the decision was made to pursue the field assembly version of the product, detail design work began on the various components. Two distinct versions had to be created for the two types of PV frames that are used on most of the modules installed by PowerLight. These types are frames with an internal flange and frames with an external flange. The designs of these two versions were kept as similar as possible. The design went through several iterations, and prototypes were made for many of the iterations. A set of prototypes were constructed for evaluation as shown in Figure 63 and Figure 64 in PowerLight's Berkeley facility.

As the design progressed, the wind performance was studied through a combination of computational fluid dynamic (CFD) modeling and wind tunnel testing. The CFD work served to optimize the design. The resulting configuration was then tested in the wind tunnel to gauge actual performance and the required weight of the array. The design was again refined based on the results of the wind studies.

Figure 63: Prototype Gen II Radiant Barrier Tiles for Flat Roof

Photo Credit: PowerLight Corporation

Figure 64: Prototype Gen II Radiant Barrier Tiles for Flat Roof
Photo Credit: PowerLight Corporation

3.7 Final Product

3.7.1 First Commercial Installation

The first full-scale array was installed at a customer's site in December 2004. For the most part, the installation went extremely well. It was assumed that the installation time for the Radiant Barrier Tiles would be longer than that for the Gen II Insulated tiles since the assembly was done on the roof during installation. However, it was found that the installation time was nearly the same as for the insulated tiles. The main reason for this is that the design of the Radiant Barrier Tiles makes them self-aligning during the installation, which means that the installers do not have to be as careful to line everything up as they go. Also, since the same size fastener is used for all the connections, only one tool is required.

The first large-scale array in California is schedule for installation in July 2005.

3.7.2 Manufacturing Process

The Radiant Barrier tile for flat roof is intended to be assembled at the job site. As such, there is no in-house manufacturing at PowerLight. PowerLight has set up a supply chain for this product. By working closely with these suppliers during the design process, ease of manufacturing was factored into each design iteration. As described above, the assembly process on the roof was faster than expected.

3.7.3 Production Data and Photos

The first full-scale array was installed in December 2004. The array is shown in Figure 65 through Figure 68 as it is assembled on the customer's roof.

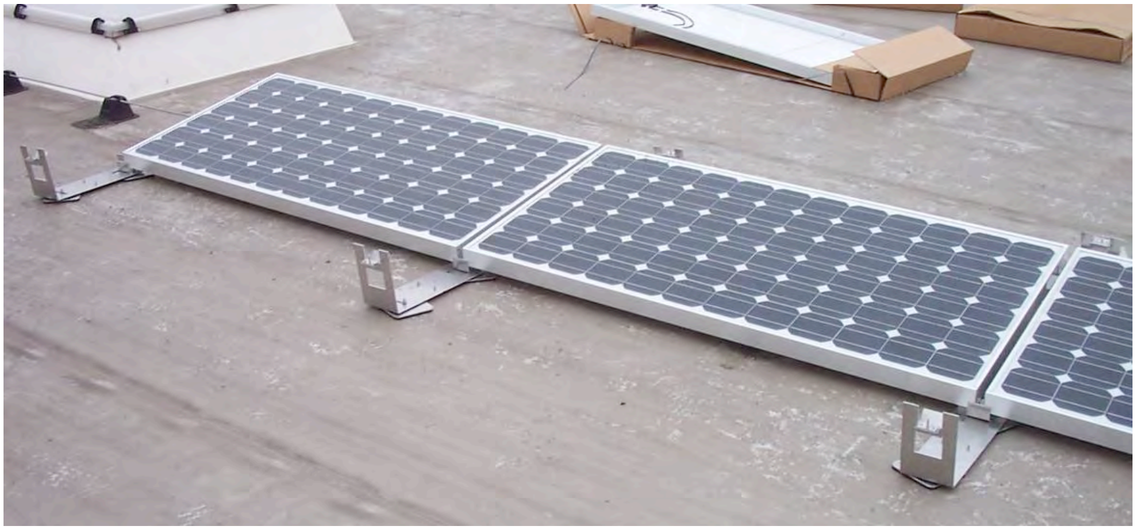

Figure 65: Assembly process started
Photo Credit: PowerLight Corporation

Figure 66: Partially completed array
Photo Credit: PowerLight Corporation

Figure 67: Wind deflectors installed
Photo Credit: PowerLight Corporation

Figure 68: Completed array
Photo Credit: PowerLight Corporation

3.7.4 Certifications

As with the Gen II Insulated Tile for flat roof, PowerLight implemented a comprehensive internal test program that duplicates the certification tests prior to submitting the design to UL and ICC. The purpose of this was to ensure that the design submitted would pass the actual certification testing. The certification testing is a lengthy and expensive process, so it was important to go through it only once, after the design reached its final form.

As with the Gen II Insulated Tile for flat roof, the final design of the Gen II Radiant Barrier Tile incorporates the use of framed PV modules. Each of these modules carries a UL listing independent of the mounting method. For this reason, the only part of the mounting system requiring UL listing was the grounding clips. UL listing has been obtained for these parts.

ICC certification has been applied for, and the design is being evaluated.

3.8 Electrical Performance

On February 22, 2005, PowerLight installed a 1.7 kW array consisting of a 3x3 array of Gen II Radiant Barrier tiles for Flat Roofs in Rancho Cordova, California. This site was chosen for its hot weather climate and location within SMUD territory. The main purpose for the test was to study the thermal and electrical performance of the Gen II Radiant Barrier system. Using PowerLight's internal balance-of-system power rating tool, PowerRater 1.3™, the array's predicted power output is 1.38 kW_{ac} for standard testing conditions.

Unfortunately, due to problems in the power from the electrical grid, the inverter was unable to track the power. This resulted in the inverter tripping off repeatedly after several minutes of operation. The inverter manufacturer verified that the inverter itself did not have a problem, but this issue could not be resolved by the time of this report. Fortunately, almost a full hour of data was collected on April 12, 2005. During this time, the inverter tripped off only a few times, and the irradiance was consistent. Normalizing the data to an irradiance of 1000 W/m^2 (1000 W/m^2 is used by PowerRater 1.3™) the power output was calculated to be 1.23 kW_{ac}. The greatest contributor to this discrepancy between the predicted and measured power output was most likely the tripped inverter. The exact impact that this had on the power output could not be determined because the exact number of times the inverter tripped off and the duration of each down cycle is unknown.

Though the electrical performance dataset is incomplete at this time, the results are not expected to vary dramatically from the predictions given the measured thermal performance. PowerLight will continue to monitor this array once the electrical supply issues are resolved to verify predicted electrical performance.

3.9 Thermal Performance

By the time of this report, April 16, 2005, was one of the hottest days during the testing period with the most consistent irradiance. The maximum ambient temperature for this day was 82°F with temperatures over 70°F being maintained from 10:15 a.m. to 6:30 p.m.

Figure 69 shows the temperature data for all the thermocouples located at the central Gen II Radiant Barrier Tile (as described in Figure 70 below) as well as the irradiance and ambient temperature for the entire day of April 16, 2005. The maximum temperature of the PV laminate was 153°F. All other temperature measurements, including the air gap temperature, were within 13°F of ambient temperature.

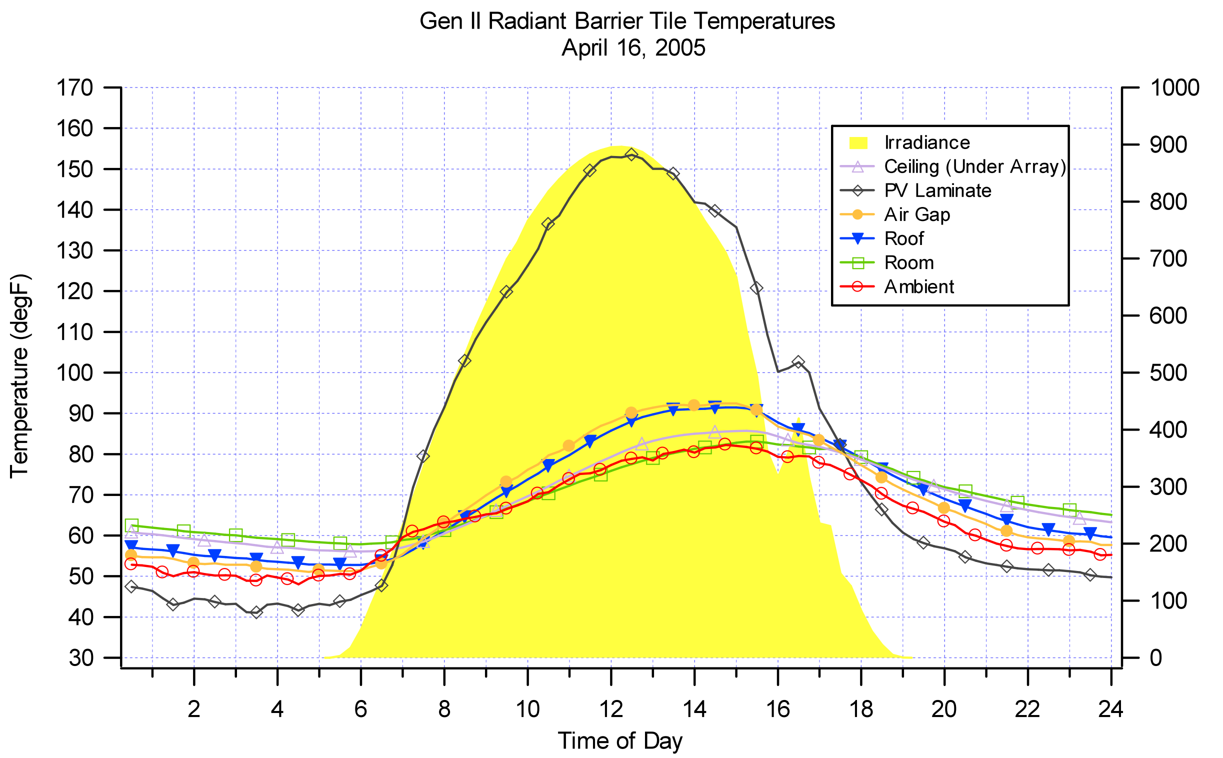

Figure 69: Gen II Radiant Barrier Tiles temperatures

Photo Credit: PowerLight Corporation

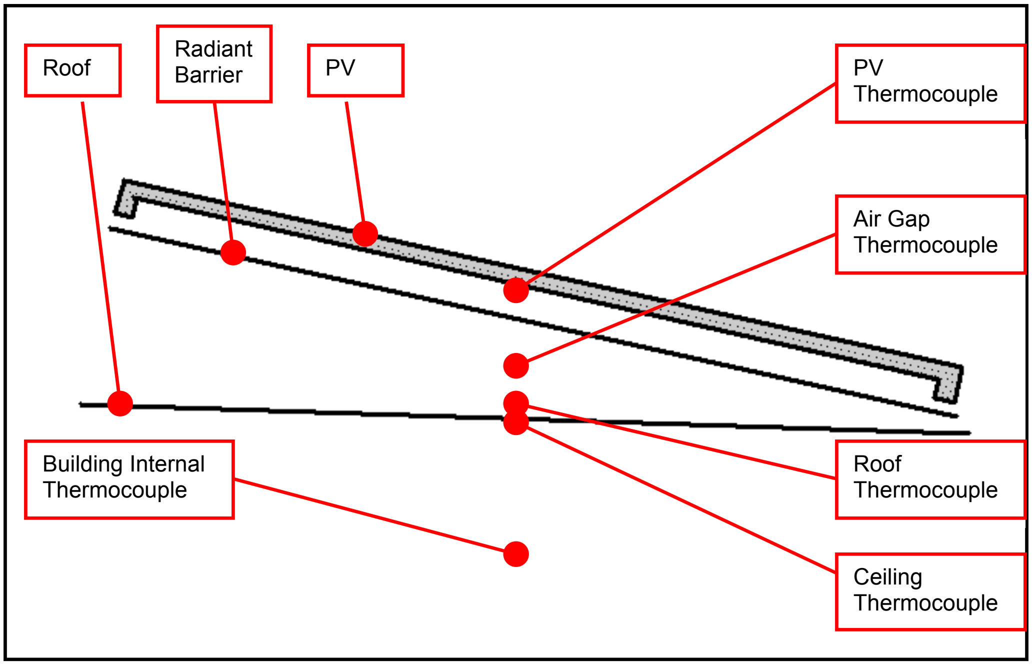

Figure 70: Thermocouple locations

Photo Credit: PowerLight Corporation

Figure 71 shows the temperatures of the roof and ceiling under the central Gen II Radiant Barrier Tile, and Figure 72 shows the roof and ceiling temperatures at the control location. The roof temperature under the Gen II Radiant Barrier Tile stayed within 11°F of ambient. At the same time, the roof temperature at the control location rose 51°F above ambient. Between 10 a.m. and 6 p.m., the average ambient temperature was 78°F. During the same time, the roof temperature under the radiant barrier averaged 86°F while at the control location the average was 113°F.

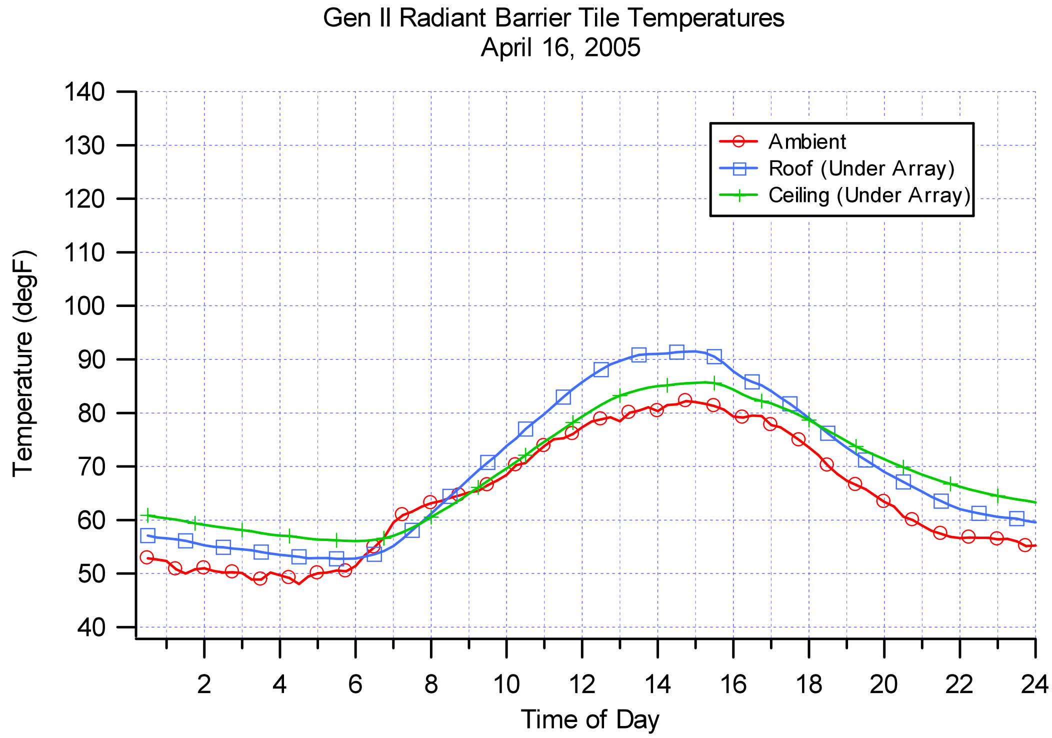

Figure 71: Roof and deck temperatures under the central tile of the array.

Photo Credit: PowerLight Corporation

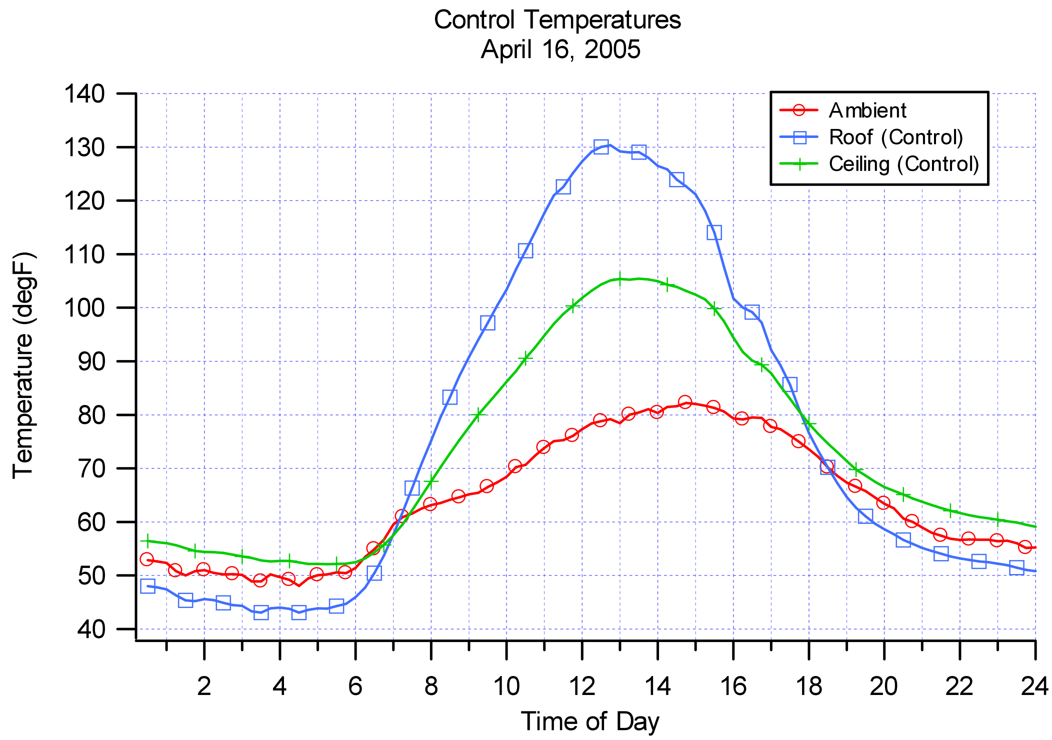

Figure 72: Roof and deck temperatures at control location.

Photo Credit: PowerLight Corporation

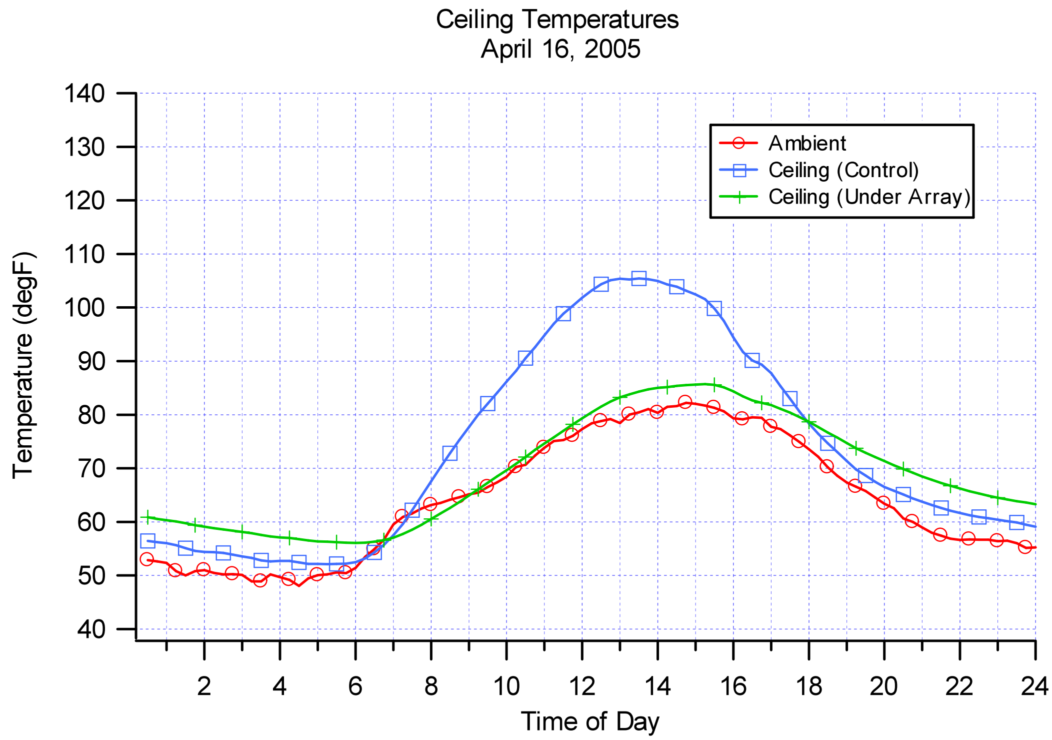

Figure 73: Under-deck temperatures.

Photo Credit: PowerLight Corporation

More importantly, Figure 73 shows that the ceiling temperature underneath the Gen II Radiant Barrier array stayed much cooler than at the control location. Between 10 a.m. and 6 p.m., the ceiling under the array averaged temperatures 15°F cooler than the ceiling at the control location. This reduction in ceiling temperature is critical because the ceiling is the interface where the roof transfers its heat to the interior of the building. Steven Barkaszi from the Florida Solar Energy Center considers this a significant reduction in temperature that should yield substantial yearly energy savings.

A minimum of several weeks of hot weather data (more than 25°C /77°F) are necessary to reasonably estimate the HVAC energy savings to the building. Unfortunately, from the time of installation to the writing of this report there were only five days where the ambient temperature was 25°C or greater. This is not a large enough dataset to run an accurate simulation. PowerLight will continue to collect data from the site so that the HVAC energy savings can be estimated.

3.10 Cost

The cost of this product has not yet reached the goals set out at the beginning of this project. Currently, material cost is approximately 30% higher than the goal. Some of this is due to the jump in the cost of steel midway through the project. Some of it is due to modifications in the structural design in response to wind tunnel studies. Nonetheless, assembly and installation labor is lower than anticipated.

The power output of the PV modules being used has gone up over the course of this project. More and more, the cost of energy (kWh) is becoming more important than the cost of total capacity (kW). Though the cost is higher than hoped for, the cost of energy is competitive with other products on the market that are offered by other companies as evidenced by PowerLight's recent success in selling this product in competitive bids.

PowerLight is dedicated to continuous improvement, and this includes always looking for ways to reduce cost. As PowerLight moves forward with the commercialization of this product, the company will look for ways to improve cost through design improvements, process improvements, and supply chain partnerships.

3.10.1 Residential Markets

The residential market is divided between sloped roof and flat roof buildings. It is important to pursue both of these markets to provide maximum proliferation of PV products. The flat roof market is relatively untapped. There are many products offered for the sloped roof market, but the product developed during this project has addressed some of the shortcomings of these existing products. PV efficiency is increased. Heat transfer to the building is decreased. Installation processes are improved, and the replacement of any broken modules has been made much simpler.

3.10.2 Commercialization Potential

PowerLight is moving forward with the commercial launch of this product. One large-scale commercial system has already been installed at a customer's site. The first large Californian project has been sold and is scheduled for installation in July 2005. Many large systems have been quoted to potential customers in a variety of locations in California, in other states, and overseas. Feedback from installers and potential customers has been very favorable.

3.11 Continued Focus

3.11.1 Electrical Performance

It is important to maximize electrical performance of the tile. The production of electricity is the primary function of the system, so it must be given the highest priority. While the electrical performance results are inconclusive at this time, the performance of PV modules at a given temperature is well known, so there are unlikely to be any surprises in electrical performance. Nevertheless, it is vital to work continuously toward improved electrical output of PV systems. This is necessary to the continuous improvement of the cost of energy from PV. The main method for improving electrical performance of the Gen II Radiant Barrier Tile will be looking for ways to optimize the flow of cooling air around the modules and the incorporation of higher efficiency modules into the design as new technologies become available.

3.11.2 Thermal Performance

The thermal benefits of the Gen II Radiant Barrier Tile can be seen from the graph of roof temperature. A roof completely covered with this product will have a lower heat flux into the building than a similar bare roof. Nonetheless, as discussed in Section 2.12 above, this benefit will be valued by some customers and not others. Customers who do value the thermal benefit are likely to want the Gen II Insulated Tile because it completely covers the roof, providing a more complete insulating layer. The customers who do not value the thermal benefit are likely to prefer the lower cost of the Gen II Radiant Barrier Tile, but are likely to prefer the same product without the cost of the radiant barrier itself. PowerLight recommends focusing on optimizing the PV temperature instead of doing more work to reduce the heat flux into the building with this product. The product is design in such a way that the radiant barrier can be easily included for those customers who value the thermal benefit to the building.

3.11.3 Cost

Cost reduction will remain a high priority for all types of PV systems until they can compete with other forms of electricity production without buydown programs. It is a top priority for PowerLight to look continuously for ways to reduce the cost of this product as well as all of the others offered by the company. All aspects of the tile must be examined on a periodic basis for ways to reduce the cost of materials, labor, and overhead.

4. Benefits to California

The achievements realized during this project provide many benefits to the citizens of California. The technical objectives set out at the beginning of this project have led to the development and commercial availability of a high-value PV product for sloped-roof buildings, as well as new high-value PV products for flat-roof buildings. The progress made toward these goals will do much for California building owners in reducing energy costs, both through lowering consumption and maximizing PV output.

The UL listing and Class A fire rating for the residential product will streamline the permitting process and make developers and building inspectors confident in the safety of the product. With the PV shingles designed to mate with an existing and well-known roofing product, market penetration can be accelerated, allowing California homeowners to enjoy the benefits of the new BIPV products more quickly. The final electrical wiring design allows for easy removal of any PV laminate and easy access to the electrical connections when removing a laminate. The long design life of the product and the ease of replacement will keep maintenance costs of the system to a minimum, providing maximum return on the homeowner's investment. Initial feedback on the new product indicated that its aesthetics are being well received from industry representatives and customers. The design blends well with roofing tiles that are being used in many new California home developments.

The new products are designed for new or retrofit and building-integrated applications. They are simple to install using traditional roofing practices. Electrical wiring and interconnection are integrated into the mounting system and are accessible after installation. Electricity and thermal performance is expected to be capable of recognition by California Energy Commission Title 24. This will speed the proliferation of the new products, allowing California building owners a way to reduce their energy costs in the very near future.

The products are expected to meet the commercialization objectives of the project. PowerLight continues to work on lowering these product costs. The successful launch of these new products provides many benefits to the people of California.

Solar-electric power systems provide a domestic source of energy that is plentiful, sustainable, and available throughout the United States. PV systems transform clean, abundant solar energy into electricity, are virtually maintenance free, and provide an economic hedge against volatile fossil fuel prices. These on-site solar systems provide renewable power for more than 30 years and offset purchases of expensive "peak" utility electricity. Solar powered installations spare the environment from thousands of tons of harmful emissions, such as nitrogen oxides, sulfur dioxide, and carbon dioxide, which are major contributors to smog, acid rain and global warming. One MW of solar installations will reduce emissions of nitrogen oxides by an estimated 8 tons and carbon dioxide by 32,000 tons. Building a PV infrastructure provides insurance against the threat of global warming and climate change.

In the past, the main problem with generating electricity from the sun through PV has been cost. Because of projects like this one, PV now makes not only environmental sense but economic sense as well. A direct result of the State's continued commitment to this indigenous resource is economic development and the associated jobs. These benefits will continue to be realized with the widespread adoption of PV.

The technical objectives set out at the beginning of this project have led to the development of high-value PV products. The successful launches of these new PV products provide broad target groups with aesthetically pleasing, safe, market ready, and more affordable PV options.

Glossary

AC	Alternating Current. An electric current that reverses direction. In America, most household current is single-phase AC at 60 hertz.
Amps or Amperage	The unit of electrical current. Can be thought of as the "flow rate" of electricity.
Array (photovoltaic)	A group of modules wired together (in a series and/or in parallel) to form an array of solar modules.
BIPV	Building-integrated photovoltaics.
Cell (photovoltaic)	The smallest unit of a solar module. A typical a-Si solar cell is rated at 1.5 volts. A typical crystalline solar cell is rated at 0.5 volts.
Components	Refers to other devices used and needed when building a solar system.
DAS	Data acquisition system.
DC	Direct Current. An electric current flowing in one direction only.
FSEC	Florida Solar Energy Center.
GCR	Ground cover ratio.
Grid-Connected (photovoltaic)	A photovoltaic system in which the PV array supplies power directly to a load center (i.e. AC Service Panel) in a home or commercial facility. There is typically no on-site storage device included with a grid-connected photovoltaic system. Instead, all the kilowatt-hours generated by the PV system are either used by the loads connected to the load center in the building or they are pulled into the utility grid power lines via the utility kilowatt-hour meter attached to the building.
GW	Gigawatt.
HVAC	Heating, ventilation, and air-conditioning.
ICBO	International Conference of Building Officials (now ICC).
ICC	International Code Council (new name for ICBO).
IEEE	Institute of Electrical and Electronics Engineers.
Inverter	An Electronic Device that changes direct current (DC) to alternating current (AC).
kW	Kilowatt, 1000 watts; a typical incandescent light bulb uses 40-100 watts.
Module (photovoltaic)	PV modules are manufactured and assembled using solar cells, interconnect wire, bypass diodes, encapsulant (which is a top cover over the solar

cells) and a protective back sheet behind the solar cells. Most solar modules also include a frame around the edges of the back sheet/top cover assembly. Together, all of these components form the solar PV module.

MW	Megawatt.
NEC	National Electric Code.
O&M	Operation and maintenance.
PIER	Public Interest Energy Research.
Photovoltaic (PV)	Direct conversion of light into electrical energy.
Photovoltaic Cell	The treated semiconductor material that converts solar irradiance to electricity.
RD&D	Research, Development, and Demonstration.
SBIR	Small Business Innovation Research.
Series Connection	Connection in which the current (amps) flows sequentially through all of the circuit elements.
Solar	Using energy derived from the sun.
Solar Collectors	A device designed to capture light or heat energy from the sun. Solar thermal collectors are used in solar hot water systems (often found in homes) and photovoltaic collectors are used in solar electric systems.
Solar Panel	Another name for a single module or a group of solar modules that are part of a solar electric PV system.
Systems; Balance of Systems	Solar electric systems include the photovoltaic array and the other components that allow these solar panels to be used in homes and commercial facilities where a regulated DC power supply or an AC power supply is required. Components used in solar electric systems include; wire and disconnect devices, charge regulators, inverters, metering, and grounding components.
UL	Underwriters Laboratories Inc.
Volts (V)	The unit of electromotive force that will force a current of one amp through a resistance of one ohm.
Voltage	The measurement of the force of electricity.
Watts	A measure of electrical power that is determined by multiplying the voltage by the amperage.
XPS	Extruded polystyrene.